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CONTENTS

PAGE

FRONTISPIECE: R.M.S. "QUEEN MARY" - - - 156

THE LIGHTING AND TELEPHONE SYSTEM OF THE R.M.S. "QUEEN MARY."

PART I.—LIGHTING SYSTEM - - - - - 157
By T. E. Ritchie and E. H. Penwarden.

PART II.—TELEPHONE SYSTEM - - - - 171
By C. Wallace Saunders and G. H. Shelley.

THE DEVELOPMENT OF LARGE RADIO TRANSMITTING VALVES - - - - - - - - - 176
By R. Le Rossignol and E. W. Hall.

METALCLAD SWITCHGEAR AT CARDIFF - - - - 191
By A. M. Anderson.

AUTOMATIC CONTROL OF ROAD TRAFFIC—PART I. - - 202
By F. A. Downes.

THE TESTING OF LARGE ALTERNATING CURRENT CIRCUIT BREAKERS.

PART IV.—TRANSFORMERS AND REACTORS - - 213
By J. Goodman.

PART V.—INSTRUMENT EQUIPMENT - - - 218
By J. S. Cliff.

POWER PLANT REORGANIZATION AT HAMSTEAD COLLIERY 225
By B. S. Pelton.

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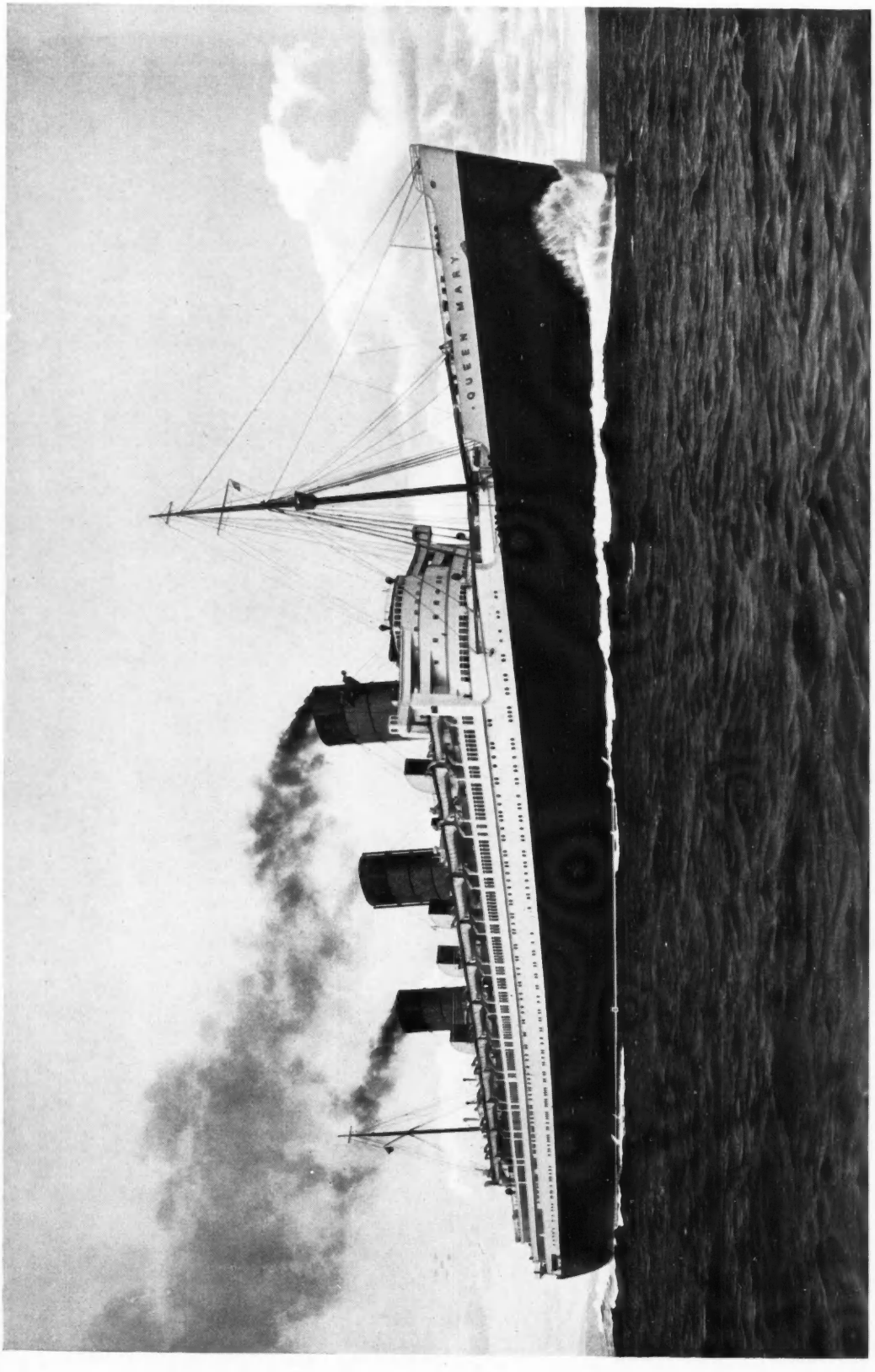


R.M.S. "QUEEN MARY."

The General Electric Co., Ltd., was responsible for the manufacture and installation of the lighting fittings in most of the important public rooms of this famous vessel, and, in addition, the whole of the telephone apparatus. A full description of the equipment installed starts on the next page.

G.E.C. Journal

VOL. VII. AUGUST, 1936. No. 3.

The Lighting and Telephone System of the R.M.S. "Queen Mary."

PART I.—LIGHTING.

By THOMAS E. RITCHIE, A.M.I.E.E.
Chief Illuminating Engineer, The General Electric Co., Ltd.,

and

EDGAR H. PENWARDEN
Chief of Fittings Design Office, The General Electric Co., Ltd.

The planning of the lighting scheme of the "Queen Mary" first took shape many years ago—long before her keel was laid down in 1930. One of the authors of this article was associated with the officials of the Cunard-White Star Company in this preliminary investigation, and both were largely responsible for the lighting schemes of the most important public rooms in the ship.

In this article they briefly discuss the special requirements of lighting fittings for marine use and describe those installed in the "Queen Mary."

THE lighting of the Cunard-White Star liner, *Queen Mary* is a triumph of modern illuminating science. The results achieved combine a measure of beauty and efficiency unrivalled in any liner hitherto built, and are the outcome of careful planning and co-operation between architects, designers and builders. This co-operation and the immense amount of detail co-ordination which is involved, are, of course, essential in every lighting scheme of magnitude, whether on land or sea. In the case of the *Queen Mary*, special conditions were encountered which rendered such a scheme highly complicated.

It is therefore proposed, first, briefly to discuss the requirements demanded of lighting fittings employed for marine work before describing those installed on the *Queen Mary*.

DESIGN OF LIGHTING FITTINGS FOR MARINE WORK.

The construction and design of lighting fixtures for marine work must be based on a specialised knowledge of service conditions.

It is essential that in designing lighting fittings for use on board ship, the necessity of rigidity must always be borne in mind and the construction and method of fixing and supporting must be such as to ensure that undue movement is effectually prevented.

The ventilation and air conditioning of a large ship is not only an exceedingly complicated problem, but is also one which should be closely co-ordinated with the planning of the lighting installation and the construction of the fittings. The large amount of electrical energy demanded by modern methods of illumination, involves the removal from the interior of the fittings of a correspondingly large

Fig. 1.—Cabin class main restaurant showing lighting trough fittings on low level ceiling and semi-recessed square fittings on intermediate level ceiling.

quantity of heat. Ventilating ducts are therefore placed above, and are connected to many of the larger lighting units and the heat from the lamps is extracted through these ducts.

Whilst the removal of the heat in this way is of the greatest importance in keeping the lamps and the interior of the glassware reasonably cool, it does not have material effect upon the temperature of the room in which the fittings are installed. Separate grilles are usually provided for dealing with the ventilation of the room, but the *Queen Mary* is believed to be the first ship in which the grilles for the extraction of the heated and impure air from the rooms are in many cases incorporated in the lighting fittings.

Conservation of space is of paramount importance in all ship work, and cable runs, junction boxes, ventilating ducts and the like, to which quick and convenient access is essential, are therefore mounted above or behind the lighting fixtures. In such cases the fittings have to be specially constructed to provide this access.

Special fixings have to be provided in the steel structure; shaped openings, accurate in size and spacing, have to be cut in ceilings or walls, and sight lines have to be determined to enable the correct sections to be drawn of cornices or fixtures concealing lamps, while the design of the fittings themselves, and the methods of mounting, etc., must be subordinated to the limits imposed by the structural requirements of the ship.

The enumeration of these salient points reveals the need of foresight and scrupulous attention to detail by the architect in the early stages of the planning of the decorative treatment of the rooms, and also the necessity for the close co-operation and co-ordination of detail previously mentioned between the architect, the various building contractors and the fittings designer.

GENERAL LIGHTING SCHEME.

In the cabin class accommodation of the *Queen Mary*, a large number of the public rooms have been illuminated by fittings supplied and manufactured by the G.E.C.; these include the restaurant, lounge, smoke room, tea and dance room, observation lounge and cocktail bar, private dining rooms forward, long gallery, starboard gallery, entrance vestibule to the restaurant and lounge, and the main lighting in the swimming pool. In the tourist accommodation the main deck lounge, dining saloon, smoke room, cocktail bar, "A" deck lounge, library and writing room, children's room, and main and aft staircases, have G.E.C. lighting; and fittings of similar manufacture are used for the dining room, smoke room, lounge, garden lounge, and entrances in the third class accommodation.

Fig. 2.—Central area of main restaurant showing lighting fittings in high level ceiling, frieze lights and torcheres.

The details of the various lighting devices given in the following description, relating to some of the principal apartments, are necessarily of the briefest character.

Many thousands of electric lamps were needed,

a large proportion of these being Osram lamps of various types ; including lamps for the stage lighting battens and floods, projector lamps for "spot" and special effects, architectural lamps for decorative illumination, lamps for signalling devices, and for many other uses ; in addition, the company supplied over 200 directional signs, 640 wardrobe lighting units, and 7,000 Roanoid lighting fittings. Incidental to this are the 5,000 switches supplied, also the circuit-breaker distribution boards for the lighting of crew spaces, connection boxes, and other essential items.

CABIN CLASS ACCOMMODATION.

Main Restaurant.

In the main restaurant, figs. 1, 2, 3 and 4, the illumination is a combination of direct and indirect lighting, forming a decorative scheme in keeping with the architectural treatment of the room.

The main source of illumination in the area covered by the high and intermediate level ceilings is from two torcheres, fig. 3, located on the centre line of the floor. In the top of each, four silvered glass reflectors are concealed, accommodating obscured projector type lamps of 1000 and 500 watts, by means of which the ceilings and walls are flooded with light. These units are particularly attractive, and form a part of the decorative conception of the room. The impression of undue solidity and heaviness frequently associated with lighting features of this type is avoided by the introduction of luminous glass relief.

Auxiliary lighting is used in the ceiling decoration. Six concealed lighting cornices running fore and aft provide bright bands of light to accentuate the linear treatment of the ceiling.

The high level ceiling, fig. 2, is relieved with 22 flush pressed glass ceiling fittings. In spite of their height and the intense light projected on them from the torcheres below, they are clearly defined without being obtrusive.

Fig. 4.—Cabin class main restaurant showing low level bay starboard side, aft end.

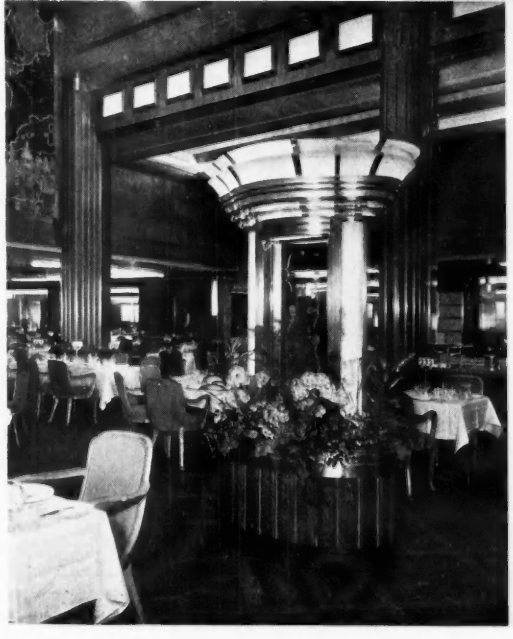


Fig. 3.—Detail of torcheres and illuminating decorative glass motifs in main restaurant.

On the intermediate level ceiling ten similar ceiling fittings of semi-flush type are installed. In these the pressed glass panels are surrounded with narrow pink-tinted flashed-opal panels decorated with engraved lines, forming a deep bevel edging. Along the frieze between the high and intermediate level celing, 48 rectangular moulded glass panels are introduced. The illumination of the area covered by the low level ceiling, fig. 4, is mainly derived from a series of trough lights running fore and aft, and surrounding the funnel hatch. There are 43 of these units some of which are as long as 18ft. 6ins. The visible metal work is designed to accentuate the linear effect. The glazing is a combination of pressed glass panels and engraved pink flashed-opal glass. At each end of the narrow troughs illuminated motifs are introduced, connecting them with the decorative treatment of the dumb waiters which are

built on the sides of the panel cases enclosing the pipe trunks.

Surmounting each of the outboard window bays illuminated cornices are installed. There are 18 of these, totalling 242 feet in length, glazed with bent pink flashed-opal glass panels and equipped with architectural lamps.

edge. They are illuminated by 12 clear tubular lamps each backed with a silvered metal reflector.

Small model lighthouses are also illuminated, and a model of the ship moves across the ocean on the map, showing her progress day by day.

Over 2,000 lamps of various types are used in these fittings giving a total lighting load of 85 kilo-

Fig. 5.—View looking forward in cabin-class main lounge showing comprehensive decorative lighting scheme.

Each of the 52 bulk-head windows is equipped with concealed mirror-lined trough reflectors to illuminate the peach-tinted plate glass windows inboard. The outboard windows are masked by a sliding panel, painted a matt white to form a reflector for the artificial lighting equipment. On the narrow panels between these windows, 34 semi-recessed panel brackets are introduced.

Four similar fittings form luminous decorative motifs on the panels above the dumb waiters against the funnel hatch, and four similar motifs are used on the jardinieres with the addition of narrow soffit lights to illuminate the flowers.

On the pillars between the high and intermediate level ceilings (see fig. 1) are eight elongated recessed metal panels each of which has three demi-coupe brackets. These distinctive units are designed to eliminate as far as possible, by the application of an efficient light source, shadows cast by the pillars on the intermediate level ceiling from the concentrated light sources in the two central torcheres.

On the large map on the wall against the funnel hatch (see fig. 2), interesting features are found in the form of an illuminated sun motif and clock face. The chapters of the clock dial are blocks of special white glass inserted into the panel on the

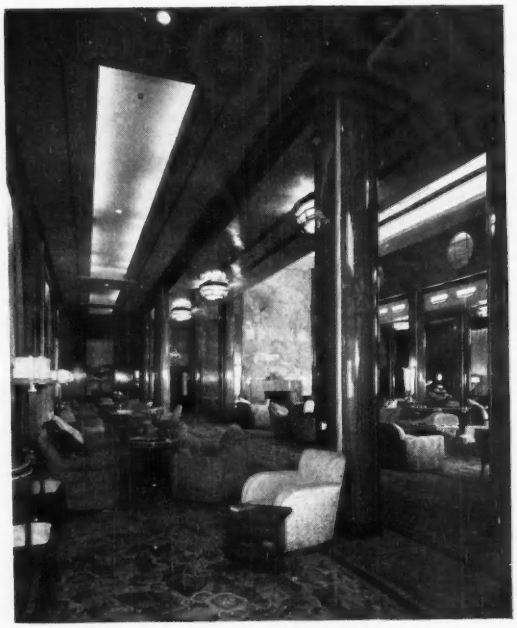


Fig. 6.—Cabin class main lounge. View on port side looking forward showing concealed lighting casettes and oval ceiling fittings in low level ceiling and decorative floor standards against outboard windows.

watts. It is of interest that all the sheet metal reflector boxes had to be made removable to allow access to the cable runs, junction boxes and ventilating trunks, and are lined with felt, and fixed with spring washers to avoid rattle. Captive screw fasteners are fitted to all doors, as well as concealed openings for ventilation. All glass panels are lined with felt round their edges, and glass clips with slotted holes fitted to ensure firm fixing without producing undue pressure. All silver-bronze metal work in these and the remainder of the fittings described is of "Delta" brand.

Cabin Main Lounge.

The lighting effects in the cabin main lounge, figs. 5 and 6, are part of a decorative scheme of notable beauty. The metal work of the principal units is electro-gilt, having a matt finish and a burnished relief.

The panelled treatment of the high level ceiling is enriched by 14 flush laylights, glazed with peach-tinted glass. The box reflectors of these units are recessed in the ceiling and are provided with hinged doors for access from above for maintenance purposes. Architectural lamps are employed and are arranged

Fig. 8.—View of cabin class smoke room showing systems of lighting in high and low level areas.

Fig. 7.—Golden onyx vase fittings and recessed panel fittings in frieze of main lounge.

in alignment with the glazing bars in order to provide a moderate surface brightness on the glass as well as an auxiliary light source. Two coves, concealing wiring channels equipped with lamps, produce bright bands of light forming a linear surround to the laylights. In the top frieze are 10 circular daylight windows behind which reflector blinds are drawn at night to form a reflecting surface for artificial illumination provided by lighting troughs which are lined with mirror glass, and concealed in the space above the windows. Around the lower frieze are 28 recessed panel fittings, each having three silvered glass reflectors equipped with opal lamps. The reflectors are masked by a glazed band along the bottom of the opening, the light being projected directly on to the ceiling, thus providing the main source of indirect illumination. A gilded curved recessed metal reflector forming the background of the opening serves as an additional coloured light source in harmony with the decoration.

On the main soffits between the high and low level ceilings are eight oval ceiling fittings (fig. 6) fixed to suspended floats masking the ventilating ducts. These are imposing decorative lighting units glazed with white and peach-tinted engraved plate glass.

The low level ceiling provides illumination in the form of recessed indirect lighting casettes.

On the walls six three-light brackets are introduced for effect lighting. The decoration of these units represent technique of a very high order. The units consist of three "U" shaped bends of peach plate glass beautifully worked with moulded sandblasting. In addition, six small trough lights conceal lamps for local lighting. The curtains and pelmets furnishing the outboard windows are illuminated from above by means of concealed trough reflectors, and the jardinieres are also provided with concealed lighting equipment.

Along each side of the lounge are eight decorative

floor standards made in electro-gilt bronze, while on the floor in the central area are eight vase-shaped pylons, 7 feet high (fig. 7). Eight obscured projector type lamps are installed in the pylons, one in each of the reflectors at the top. These fittings form auxiliary light sources for the high level ceiling and friezes.

Fig. 9.—Ceiling fittings, wall brackets and local lighting on writing tables in low level ceiling area of cabin class smoking room.

So brief a description of the lighting of this room necessarily conveys a very inadequate idea of the charm and quality of the decorative effect as a whole. The lounge, as might be supposed, is one of the most beautiful rooms on the ship, and its lighting, in particular, must be seen to be appreciated at its true value.

Main Smoking Room—Promenade Deck.

The illumination of the main smoking room (fig. 8) which is situated on the promenade deck, is also a combination of direct and indirect lighting. On the ornamental frieze surrounding the central area below the high level ceiling, eight rectangular demi-coupe brackets are used to conceal the main lighting equipment. Each of these two reflectors contains a 100 watt opal lamp which not only projects light on to the ceiling, but also illuminates the high relief symbolical panels surmounting these brackets.

The frieze between these units is panelled with decorative mirror glass. Three horizontal metal troughs intersect these panels, in each of which wiring channels and lamps are installed to illuminate them and to provide additional indirect illumination on the ceiling.

The area below the low level ceiling on the port and starboard sides, fig. 9, is directly illuminated by eight rectangular ceiling fittings. These units mask the air-conditioning ventilating ducts, and are provided with the requisite air spaces. Horizontal metal baffle plates are incorporated in the design to screen these openings.

On the low level ceiling, looking forward, five octagonal ceiling fittings are installed to match, and around the walls 16 reading lamp brackets supply local lighting.

Fig. 10.—Cabin class tea and dance room showing illuminated lay lights over tea balcony and decorative table lamps.

Cabin Class Tea and Dance Room.

The lighting of the cabin class tea and dance room, fig. 10, is designed to convey a festive atmosphere. Surrounding the ceiling of the dance area is a continuous coved trough in which concealed wiring channels accommodate lamps for white and three colour lighting. These are controlled by dimmers giving a sequence of colour-changing effects, or alternatively, constant lighting in any one desired colour. A white crystal glass fitting of unusual design, fig. 11, is fixed in the centre of the ceiling, in which clear and coloured lamps are installed. The coloured lamps are controlled by the dimmer operating the other colour changing effects, and in combination with the clear lamps

produce a brilliant feature in the decorative scheme. On the ceiling over the balcony on the outboard side, three laylights are installed, two of which are shown in fig. 12. They are glazed with peach-tinted plate glass worked with an intricate engraved decoration which involved seven distinct processes in their manufacture. The rounded corners and curved sides of the designs necessitated accurate moulding of double bent glass. They are illuminated by indirect methods, the lamps, which are concealed along each side, projecting light on to specially shaped sheet metal reflectors recessed in the ceiling above.

Five narrow rectangular glazed troughs are installed on the ceiling around the dancing space, and the curtains of the outboard windows are illuminated by lamps concealed in a coved trough running fore and aft across the room. Concealed lighting troughs are also provided to illuminate the windows at night.

The painted panel decorations on the walls are

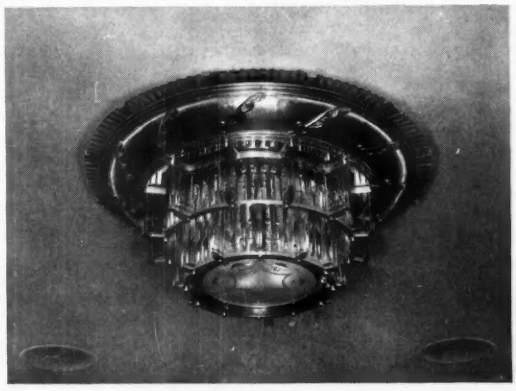


Fig. 11.—Detail of crystal glass ceiling fitting over dance floor in cabin class tea and dance room.

punctuated with four glass plaques in the centre of which vertical illuminated features are introduced, glazed with crystal glass to harmonize with the primary lighting unit over the centre of the dance floor area. The balcony balustrade is also relieved with luminous glass motifs and pedestal lighting fittings.

Cabin Class Observation Lounge and Cocktail Bar.

The cabin class observation lounge and cocktail bar, fig. 13, is semi-circular in plan and a totally indirect lighting system is employed. In addition to concealed cove lighting in the ceiling over the service bar and the windows, five pendants are installed in domed recesses in the main ceiling. These are attractive fittings in the form of circular dishes in silver bronze metal. They are cellulose sprayed in four colours and relieved with polished concentric bands of varying widths and a small shallow decorated glass dish in the centre. Trumpet shaped metal cone reflectors are fixed to the ceiling above the dishes with an air space all round. These cones

Fig. 12.—Laylights over balcony and concealed cornice lighting for window curtains of cabin class tea and dance room.

Fig. 13.—Indirect lighting fittings and effects in cabin class observation lounge and cocktail bar.

mask the ventilating ducts and special sheet metal boxing is provided in the fixture to connect up with the air extracts.

The illumination of the main ceiling is provided

for by four indirect lighting standards incorporated with the newel posts of the balustrade.

Cabin Class Long Gallery.

The long gallery, fig. 14, is indirectly illuminated by mirror lined reflectors concealed in oval metal dishes surmounting eight decorative pylons.

A very difficult lighting problem was involved owing to their enforced irregular spacing. The four main pylons were fixed nearer to the wall on the outboard side than on the inboard side, and were also of uneven longitudinal spacing.

The solution of this problem was successfully accomplished by the introduction of specially designed reflectors lined with mirror glass bends of varying reflecting qualities and shapes, as shown in fig. 15, each equipped with a 1000 watt obscure projector type lamp. The resultant illumination was remarkable for its low diversity.

Flanking the decorative painted panels on the end walls, fore and aft, four small pylons are fixed close to the wall. These units are equipped with special reflectors and obscured projector type lamps.

Cabin Class Starboard Gallery.

The illumination of the starboard gallery, fig. 16, is mainly by indirect lighting. Two continuous light troughs equipped with wiring channels and lamps appropriately spaced, run fore and aft along each side of the stepped ceiling. Four circular pendants fixed in coved circular ceiling recesses situated along the centre line of the room provide an additional semi-indirect lighting sources.

These units are made in silver bronze metal and glazed with amber tinted flashed-opal glass introducing luminous surfaces in restrained contrast to the main indirect illumination.

Cabin Class Swimming Pool.

The lighting of the swimming pool, fig. 17, is also mainly indirect. It is carried out most effectively by special silvered glass reflectors, each equipped with a 1000 watt obscured projector type lamp. These are housed in faience bowls which are built into the columns on each side of the pool.

To provide a decorative note, small trough-shape wall lights are fitted at each side of the bowls. These also serve to counteract any shadow beneath the bowls due to the powerful illumination above.

Two further reflectors are situated on the walls fore and aft, making a total of eight in all. The effect obtained is extremely attractive as the barrel shaped ceiling over the pool is lined with a synthetic mother-of-pearl material in a mosaic effect.

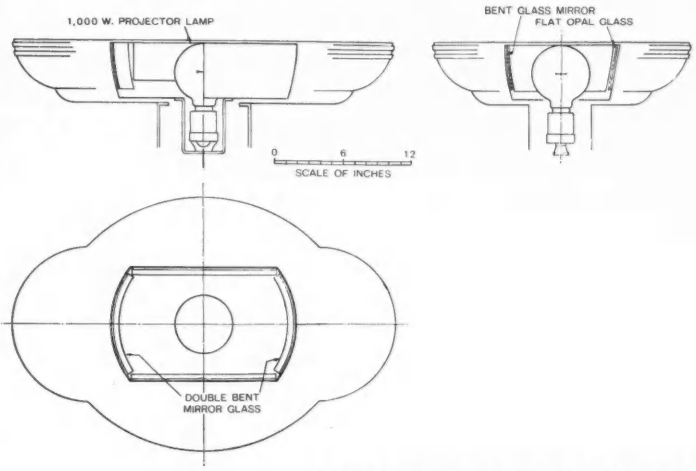


Fig. 15.—Sectional diagram of fitting in long gallery.

Fig. 14.—Cabin class long gallery showing indirect lighting standards, showcase and window lighting.

TOURIST PUBLIC ROOMS.

The illumination of the tourist public rooms is carried out mainly by direct lighting fittings, with the addition of indirect cove lighting in certain individual rooms.

No spectacular effects have been introduced, the aim having been to incorporate units of a simple and refined appearance which not only would

Fig. 16.—Cabin class starboard gallery showing lighting fittings and effects.

harmonize completely with the scheme of decoration for each room, but would provide satisfactory illumination.

Tourist Dining Saloon.

The tourist dining saloon, fig. 18, is approximately 100 feet wide by 80 feet long. On the centre, running fore and aft, are three imposing ceiling units 5 feet in diameter; the illuminated section is 2 feet in diameter, housing the necessary lamps, and having a flat ornamental surround divided into two bands, the inner being of white mirror glass having a decorative treatment, and the outer of polished silver bronze.

On the inboard port and starboard bays are six ceiling fittings similar to those on the centre line, but having a smaller decorative surround.

In the extreme port and starboard bays are 14 fittings matching those described, and together with 34 small trough-shaped soffit fittings, disposed intermediately with the larger fittings previously described, provide the main source of illumination with a total of some 200 lamps.

Interesting decorative lighting is given by the phantom illumination of a series of engraved plate glass panels fitted in the sideboard recess at the aft end of the saloon, and also by similar panels forward. The scheme is completed by the concealed lighting of the 54 windows at each side of the room, and the provision of 12-inch diameter ceiling fittings in the vestibules.

The metalwork throughout is silver bronze having a matt finish, and the glassware used is champagne-tinted flashed-opal having an ornamental engraved line treatment.

Tourist "A" Deck Lounge.

The main lighting feature of the "A" deck lounge, fig. 19, is an enclosed built-in glazed frieze of silvered bronze metal and champagne-tinted flashed-opal glass, which outlines the ceiling in the central area. The overall length is approximately 122 feet.

Immediately to port and starboard of this frieze occurs a series of illuminated glass soffit panels totalling in length approximately 80 feet, running parallel to the frieze and extending outward to the ship sides. These are of white plate glass having a linear band treatment of sandblast with brilliant "V" cut lines interposed. Illumination is provided by recessed reflectors equipped with lamps.

Two semi-detached areas aft are furnished with two rectangular ceiling fittings; these incorporate vent louvres at the top in keeping with the horizontal band treatment of the walls. Smaller fittings to match are provided in the port and starboard bays.

At each side and above the fireplace a vertical recessed panel unit 4 feet high serves to light a decorative painted metal panel and a clock over the fireplace.

Tourist Main Deck Lounge.

The tourist main deck lounge, fig. 20, has a system of indirect cornice lighting in the high level section at the aft end. This is divided into six sections intersected

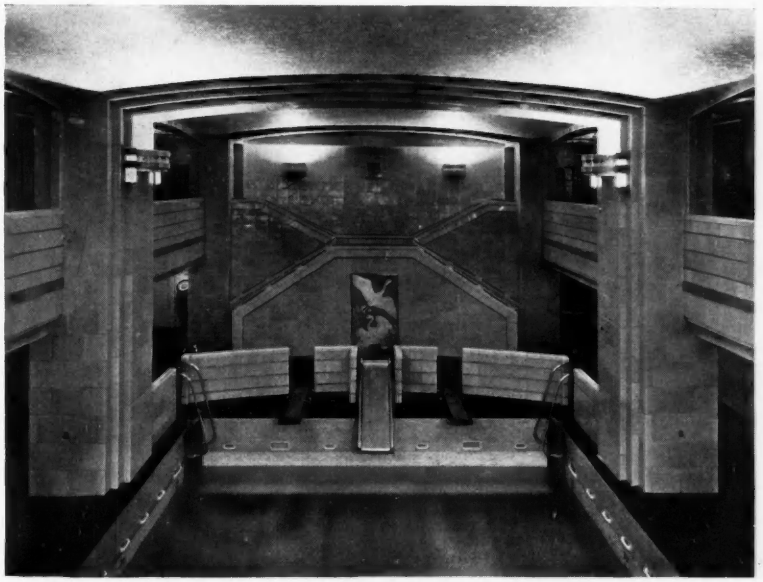


Fig. 17.—Cabin class swimming pool showing faience sconce brackets concealing lamps and reflectors for indirect lighting.

Fig. 18.—General view in tourist class dining room showing design and layout of lighting fittings.

by beams running athwart ship, and a centre beam, and a vent trunk casing fore and aft. Supplementing this are four rectangular ceiling fittings glazed with flashed-opal glass.

On the low level ceiling area are various fittings rectangular in form and glazed with flashed-opal and reeded glass.

Window lighting is by concealed reflectors, and semi-circular wall reflectors similar to those in the smoke room are employed over the writing tables and fixed seats.

As this lounge is also to be used for cinema performances, a number of pilot lights are fitted flush with the ceiling.

Tourist Smoke Room.

The smoke room, fig. 21, is lighted by means of direct lighting ceiling units, and a number of attractive wall lights fitted into the window recesses.

There are eight ceiling fittings with semi-circular ends, and having a built-in central grille for ventilation. There are a further six shallow trough shaped ceiling units also incorporating ventilation inlets.

At the forward end, on the centre, is a map and notice board illuminated by concealed architectural lamps. The 16 windows are lighted by concealed reflectors.

Tourist Cocktail Bar.

The principal lighting feature in the tourist cocktail bar, fig. 22, is a glazed cornice approximately 56 feet overall, arranged with flat, free edge, champagne-tinted opal glass panels, mounted in silver bronze metalwork. At the forward end of the room and to port of the bar is an attractive lay light glazed with champagne and pale green-tinted flashed-opal glass and decorated with an engraved design characteristic of the decoration of the room. Just below and at one end of this lay-light is an ornamental mirror lighted by a special built-in table light, and behind the bar a glass panel housing a clock having an illuminated glass dial.

Tourist Library and Writing Room.

Illumination of the library is effected primarily by flush panel fittings running parallel with the bookcases on each side of the room. Special chromium-plated reflectors recessed into the ceiling are also provided and are mainly for lighting the bookcases.

General lighting is furnished by one central ceiling fitting of silver bronze, and cellulose finished metalwork with champagne-tinted flashed-opal glass, together with several small trough shaped ceiling lights.

Fig. 19.—Illuminated cornice lighting surrounding central area and flush panel lights on low level ceiling of tourist class "A" deck lounge.

The writing room, fig. 23, is illuminated by four rectangular ceiling fittings similar in character to those in "A" deck lounge, having horizontal vent louvres for room ventilation.

Additional decorative lighting is provided by concealed reflectors in the nine windows.

Tourist Main and Aft Entrances and Staircases.

As these spaces extend through eight decks, and each has a relatively distinctive design for the fittings, it is not possible within the space available to give a detailed description for each deck level.

Special mention may be made, however, of the main entrance on the promenade deck, which has an enclosed lighting trough totalling 72 feet in length, occupying the centre ceiling area of this entrance, and lighted by 92 lamps ; in addition to this, four circular ceiling fittings are on the ceiling to port and starboard. Semi-circular wall lights occupy the niches in the vestibules, and serve to illuminate a carved figure in each niche.

Main, "B" and "C" decks have ceiling fittings which combine lighting and exhaust ventilation.

Each staircase soffit has a small circular flush ceiling light, and all lift doors have small corner trough fittings.

In the aft entrance on "A" deck a somewhat similar trough fitting to that installed on the promenade deck main entrance, measuring 62 feet long overall, provides the main source of illumination.

Aft entrances "B," "C," "D" and "E" decks have rectangular ceiling fittings as the principal source of illumination, and staircase soffits and lift doors have fittings similar to those in corresponding positions in the main entrances.

Children's Playroom.

This attractive little room, fig. 24, has a simple lighting feature along the centre of the ceiling, the silver bronze metalwork being relieved with two bands of colour running round the top and bottom mouldings. It is glazed with champagne-tinted flashed-opal glass, and is also arranged with vent grilles for exhaust ventilation.

Fig. 21.—Tourist smoke room showing arrangement of shallow lighting fittings.

Fig. 20.—Low level ceiling fittings at forward end looking to starboard of tourist class main lounge.

THIRD CLASS ACCOMMODATION.

In this section G.E.C. lighting fittings are also used extensively and figure prominently throughout many of the public rooms, such as the dining saloon, smoke room, lounges, deck entrances and other sections.

These were designed in conjunction with the decorative architect of Messrs. John Brown & Co., Ltd., and are constructed of cast silver-bronze finished metalwork, glazed with white or white flashed-opal glassware. In the garden lounge a number of trough fittings are installed for the main lighting, recessed laylights being used on the low portion to conform to the curved part of the structure. The dining room is illuminated in the main by 58 ceiling fittings.

Wall brackets to match are also installed, and several trough shaped brackets each arranged for five lamps, are fixed over the mirrors, also three recessed laylights, each illuminated by six lamps.

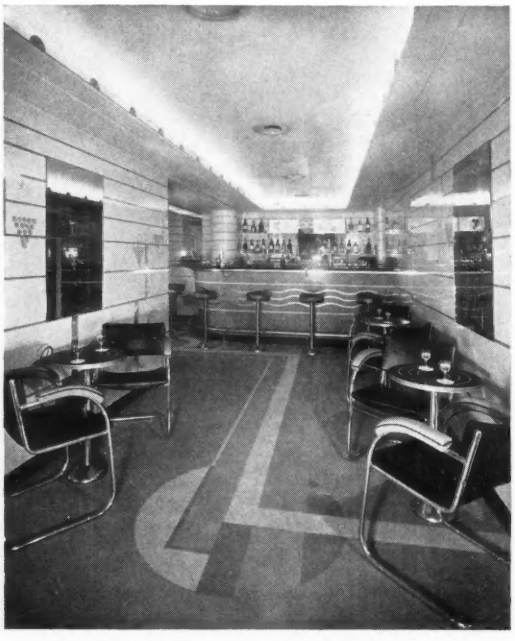


Fig. 22.—Luminous glazed cornice lighting in tourist cocktail bar.

The third class smoke room fig. 25, is illuminated by some 43 ceiling fittings with drum-shaped opal glassware, augmented by recessed laylights and a number of recessed bracket fittings to suit the shape of the partition. The various deck entrances have different types of ceiling fittings, "C" deck entrance has 6-inch globe fittings while the main deck entrance is illuminated by fittings of cylindrical glassware with similar lamp equipment. The "A" deck entrance has a number of 2-light box fittings, striplite lamps being used for the low positions. In the annexe ceiling fittings are installed, while the engineers' mess is illuminated by small cylindrically shaped ceiling fittings.

In conclusion it should be stated that the lighting schemes described were carried out by the G.E.C. in close collaboration with the architects, Mr. Arthur J. Davis, A.R.A., F.R.I.B.A. of Messrs. Mewes & Davis, F.F.R.I.B.A., and Mr. Benjamin W. Morris, F.A.I.A., of Messrs. Morris & O'Connor of New York and under the supervision and direction of Mr. J. C. Whipp, the Cunard-White Star Furnishing Department, and the shipbuilders, Messrs. John Brown & Co., Ltd. The lighting fittings in the cabin class rooms were designed by the G.E.C. in collaboration with Mr. Paul Guieu, under the direction of the architects mentioned above.

ILLUMINATION MEASUREMENTS.

The illumination intensities which follow represent the *true* average foot-candles on the working plane in the cabin and tourist class public rooms, *i.e.*, in each case they are the arithmetical mean of a series of measurements at table level sufficiently comprehensive as regards their number and sufficiently diverse and wide-spread as regards their location to ensure a really truthful result.

The importance of correct procedure in this respect, and an indication of the errors which may

Fig. 23.—Tourist writing room showing general illumination.

quite unwittingly be introduced, will be apparent if the simplest case is considered in which a square empty room of considerable size is lighted by a single fitting fixed in the centre of the ceiling. The intensity on the floor immediately under the fitting would naturally be considerably higher than that on the floor in the region of each of the four corners. If a measurement under the fitting gave, for instance, a value of 19 foot-candles, and a measurement in one of the corners a value of 1 foot-candle (which would not be in any way an extreme case), then the average intensity obtained from a single measurement under the fitting and a measurement in *one* only of the corners would be 10 foot-candles. To give such a value as the average over the whole of the room in question would obviously convey an entirely misleading impression. A lower average, arrived at in the simplest manner, would, in such a case, be obtained from a single reading of 19 foot-candles, plus four readings of one foot-candle, in the corners of the room, giving an average intensity of 4.6 foot-candles. Actually this value, although not more than 46 per cent of that obtained by the first method, would be materially in excess of the truly correct and lower value which would be obtained if the total floor area were divided into a considerable number of spaces of equal area (say squares measuring one yard each way), the illumination measured in the centre of each such space and the average value given as the mean of the whole of the readings so obtained.

In the case of the *Queen Mary* the whole of the measurements were made with a "Holophane-Edgcumbe" auto-photometer of the latest photo-electric type, the accuracy of which was specially checked prior to the carrying out of the tests. The authors are seen in fig. 26, taking one of the measurements.

In those rooms in which tables are provided, the intensity was measured either actually on the tables, in the manner shown in fig. 26, or at table level. In locations such as on settees and in deep arm-chairs, the measurements were made in the position in which a book or newspaper would normally be held.

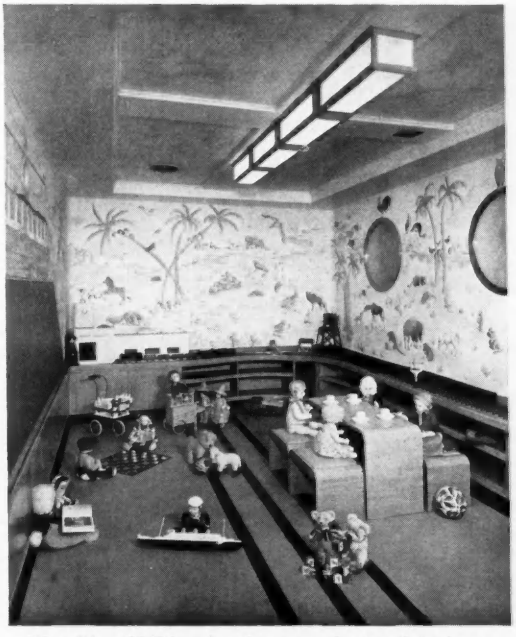


Fig. 24.—Children's playroom in tourist class showing central lighting unit.

Fig. 25.—Third class smoke room.

Care was taken to ensure that the number of measurements made in each room was sufficient to give a true average value. In the cabin class main restaurant, for example, the figures take into account not only the illumination on every one of the total of 247 individual tables (on many of the larger of which two, three or more separate readings were made), but also that on the dumb waiters and in the alley ways. Similar precautions for the obtaining of accurate results were taken in respect of each of

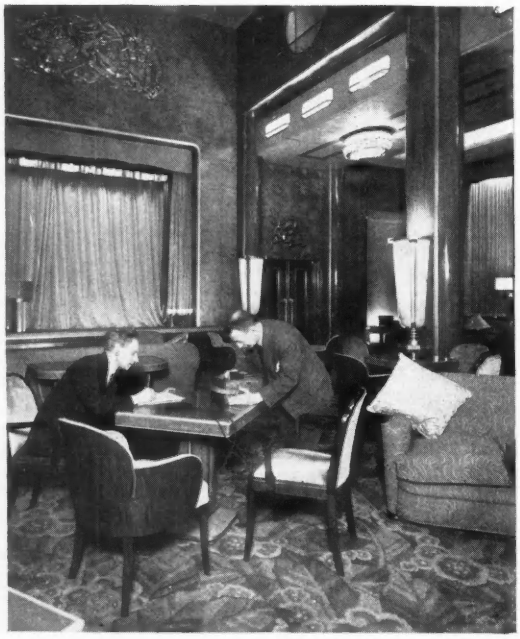


Fig. 26.—Taking measurements of illumination in the cabin class lounge.

the rooms tested—whether cabin or tourist class—and the figures given may therefore be accepted with confidence.

CABIN CLASS.

Main Restaurant.

The collective average intensity over the whole of the room is 8.2 foot-candles. In this room the total area may conveniently be divided into three sections, the central high level ceiling portion, the two intermediate level ceiling portions on either side of this and the low level ceiling portions on the port and starboard sides and around the funnel hatch at the forward end of the room. Throughout the high level area the average intensity is 6.97 foot-candles, of which 3.24 foot-candles, or 46.5 per cent, is contributed by the totally indirect lighting from the two decorative torcheres, one of which is shown in fig. 3. In the intermediate level portions the average is 6.6 foot-candles and in the low level portions 9.49 foot-candles. There is, therefore, available to those using the room a choice of two intensities one of which is noticeably lower, and therefore, to certain individuals more restful, than the other.

Private Dining Rooms.

Average intensity 7.6 Foot-candles.

Main Lounge.

Average intensity 6.47 Foot-candles.

Smoke Room.

Average intensity 4.75 Foot-candles.
Local lighting on writing tables 7.0 Foot-candles.

Forward Observation Lounge and Cocktail Bar.

Average intensity 2.5 Foot-candles.

Long Gallery.

Average intensity 3.98 Foot-candles.

Starboard Gallery.

Average intensity 2.54 Foot-candles.
Local lighting on writing tables 13.0 Foot-candles.

Tea and Dance Room.

Average intensity:
Round dancing area 3.85 Foot-candles.
On balcony 6.74 Foot-candles.

TOURIST CLASS.

Dining Room.

Average intensity 3.69 Foot-candles.

Main Deck Lounge.

Average intensity 4.7 Foot-candles.

"A" Deck Lounge.

Average intensity 6.5 Foot-candles.

Smoke Room.

Average intensity 4.6 Foot-candles.

Cocktail Bar.

Average intensity 7.4 Foot-candles.

Writing Room and Library.

Average intensity 8.67 Foot-candles.
Local lighting on writing tables 10.3 Foot-candles.
Intensity on vertical plane in centre of book shelves 9.1 Foot-candles.

PART II.—TELEPHONE SYSTEM.

By C. WALLACE SAUNDERS, M.I.Mar.E., A.M.I.C.E., A.M.I.E.E.
Manager, Marine Dept.
and
G. H. SHELLEY
G.E.C. Telephone Works.

THE planning of a telephone system, or more particularly, the application of telephone technique to satisfy the needs of a community, is always a matter of special interest to the telephone engineer when that community is an uncommon one. Rural, as distinct from city areas, present their own problems, various factors contributing to make dissimilar areas the subject of individual study. A different problem again is met in providing telephone service for ships' passengers, for in many respects a community afloat has no parallel; its members are neighbours, but strangers, a temporary assembly sharing the same house, served by a common staff, and at most times far removed from the outside world. From a telephone aspect, as from certain others also, the closest parallel to an ocean liner is the modern hotel, and it is natural to find points of similarity in the telephone services provided. Experience has shown, however, that there are many small differences—and some of them subtle—between the ideal combination of facilities required of a telephone system for ship's passengers and that for the residents in an hotel. On this account, telephone practice in the equipment of hotels offers only guidance to the designer and cannot be followed without an intimate study of life aboard ship.

The design of the telephone system for the *Queen Mary* was decided upon only after lengthy consideration of the useful facilities that the telephone could offer and after the fullest co-operation between the engineers and operating officials of the Cunard-White Star Co., Ltd., the builders, John Brown & Co., Ltd., and the telephone engineers of The General Electric Co., Ltd., to whom the contract was awarded for the entire equipment. It incorporates many of the features of earlier G.E.C. installations, notably those of the luxury liners operating between New York and Bermuda. The system is manually-operated, employing a central battery lamp-signalling switchboard, auxiliary panels for subsidiary purposes, and modern moulded handset telephones for both passengers and staff. A total of 585 lines are terminated at the switchboard which, as seen in fig. 27, are divided over three operators' positions, provision being made for concentration at times when the amount of traffic can be handled by a single operator. Provision is made for the addition of further lines up to a total of 630.

While the interconnection of lines of all classes can be effected, whatever restrictions desired being in the hands of the operators, the majority of connections can be grouped under the following four headings:—

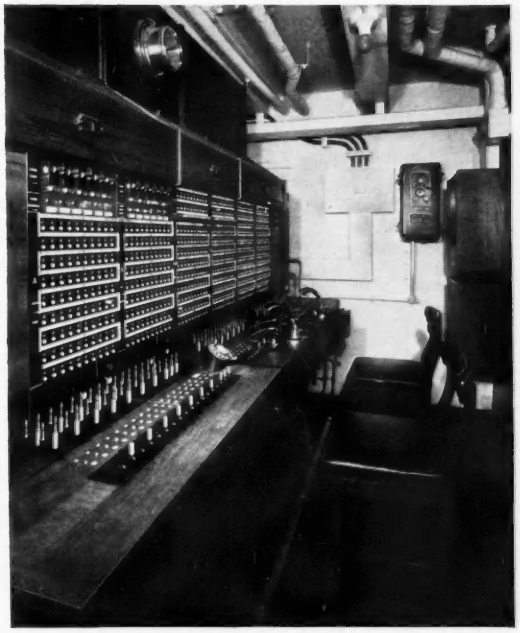


Fig. 27.—C.B. lamp signalling telephone switchboard installed in the "Queen Mary."

(*a*) *Cabins to Deck Pantries.*

This class of connection enables passengers to give meal requirements, etc. direct to the pantry serving the deck on which their cabins are situated. Each pantry is provided with three lines to the switchboard so that requirements from different points can be dealt with simultaneously.

(*b*) *Staff and General Intercommunication.*

Under this heading are all connections between staff, and between passengers by means of telephones in public parts of the ship.

(*c*) *Shore Calls in Port.*

Connection may be established by means of land lines to a shore exchange when in port, thus giving ordinary communication facilities between all parts of the ship and the public telephone system ashore.

(*d*) *Shore Calls by Radio.*

Provision is made for telephone communication

by radio link with any of the available countries when at sea, this service being given, when desired, direct from passengers' cabins.

The bulk of the telephone traffic is naturally that between the 430 cabins equipped with telephones on the Sun, Main, "A" and "B" decks and the respective pantries, one pantry serving each deck. As mentioned, three independent lines connect each pantry to the switchboard, and at these pantries orders are taken by telephone direct from the passengers.

It may be of interest to illustrate the use of the

Fig. 28.—Service staff corridor telephone.

telephone for service purposes. At the pantry the telephoned order is written on a manifold pad and one copy is despatched by messenger to the appropriate deck waiter. At the same time the order is passed over an auxiliary direct telephone circuit to the kitchen, where facilities are again provided for the simultaneous reception of orders from different points, thus ensuring that there shall be no possibility of congestion at busy times and that no delay shall take place in the transmission of orders from passengers to kitchen *via* the pantries. Continuing the example, the order is receiving attention in the kitchen by the time the deck waiter has received advice of it from the messenger. After disposing of duties in hand and upon arrival at the kitchen, the waiter may expect his demand to be met at once. It will be seen that the waiter's journey in the execution of each order is reduced to a minimum by this procedure, the importance of which may be judged when it is realized that the distance covered between a passenger's cabin and the kitchen, and back again, may exceed a quarter of a mile. Of equal importance is the rapid transmission of the order by telephone to the kitchen.

Deck waiters or stewards are posted to sections of the port and starboard corridors of each deck on which cabins are situated, each corridor being divided into six of these sections, *i.e.*, six on the port and six on the starboard side of each deck. For the use of the waiters and stewards in each section a telephone is recessed into the panelling, and in such a position that it is visible although recessed. In order not to disturb passengers in adjacent cabins, these telephones are not fitted with bells, the calling signal in each case being given by a lamp which is illuminated when the switchboard operator inserts a plug into the corresponding line jack. A typical corridor telephone is seen in fig. 28. As it is the duty of the service staff to observe lamp signals for other purposes, all calling indications are concentrated in each corridor section and a uniform method employed.

The corridor telephones enable the service staff

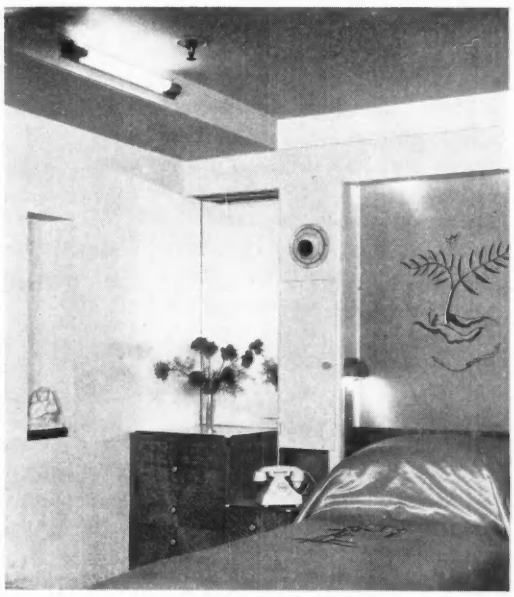


Fig. 29.—Telephone conveniently placed for bed-side use in de-luxe cabin.

to communicate with the kitchen and, by providing a means for rapid enquiry, to save fruitless journeys. Orders received personally by waiter or steward may also be transmitted direct to the kitchen or other service point for immediate attention, this facility effecting the same saving in time as in the case of orders telephoned by the passengers themselves.

From the foregoing brief outline of the use of the telephone for service purposes an idea may be

gained of its contribution to the comfort of passengers and of the need for so comprehensive a system on a vessel of the capacity of the *Queen Mary*.

A total of 135 staff and miscellaneous service lines are terminated at the switchboard, these being grouped according to the purposes they serve. For instance, service lines on the middle operator's position include those for crew bar, restaurant, kitchen, barber's shop, Turkish baths, etc., from which points mainly staff calls are made. Other lines on the middle position, such as those to the main hall (port and starboard), long gallery, port and starboard foyer, gymnasium, etc., are chiefly for passengers' use.

Staff lines appear on the third position of the switchboard and are arranged in five groups as follows :—

(1) *Navigating Staff.*

Staff captain	Fire station
Wheel house	etc., etc.
Bosun	

(2) *Chief Steward's Staff.*

Chief steward's office	Barber's shop
Second steward's office	Linen store
Kitchen clerk's office	etc., etc.

(3) *Purser's Staff.*

Purser's office	Printer's shop
Baggage master's office	Press reception room
Bank	etc., etc.

(4) *Chief Engineer's Staff.*

Chief engineer	Refrigerating plant
Staff chief engineer	Plumber's shop
Second engineer's office	Electrician's shop
Engineer's workshop	etc., etc.
Steering gear	

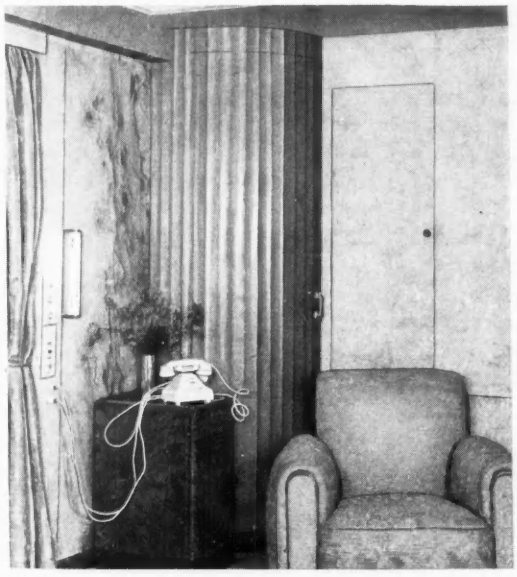


Fig. 30.—Alternative position of telephone for day use showing plug and socket connection.

(5) *Doctor's staff.*

Doctor's bedroom	Infectious hospital
Dispensary	etc., etc.
Hospital	

Two further groups of lines are those for shore connections—by radio link while at sea and by land line when in port. Passengers requiring radio calls are switched through to the radio room where the requirements are noted. When the radio link is established the telephone operator re-calls the passenger and completes the connection by means of a plug-ended two-wire circuit to the radio room. Provision is made in certain cases for the use of four-wire circuits to the radio room, should conditions for radio connection demand this. The switchboard is equipped initially for handling two simultaneous shore calls by radio, capacity being allowed for an ultimate of four.

There are ten terminations at the switchboard for connection by land line to a shore exchange when in port. The shore exchange may be of the magneto, C.B. manual or automatic type, and provision is made accordingly. The operator's dial for calling shore automatic exchanges can be seen in fig. 27. Traffic over these lines comprises passengers' calls immediately upon arrival in port and just prior to departure, and chiefly staff calls between these periods. It is interesting to note that while at Southampton, prior to the maiden voyage, the telephone system was brought into immediate use for staff and administrative calls, the traffic at once demanding the full time services of an operator.

EQUIPMENT.

Passengers' telephone instruments are of the modern self-contained type made of ivory-coloured mouldings throughout. On the front of each instrument is a printed instruction plate, in a gold-plated frame, bearing the words "Telephone Your Requirements for Room Service." To the silk covered cord a small plug is attached, and in each cabin the line from the switchboard is terminated on one or more sockets so that the telephone can be placed in the position most favoured by the passenger (figs. 29, 30 and 31). For staff use, where ivory-coloured instruments are unsuitable, black bakelite telephones of the same design are provided. In all cases, except where noise is of no account, the instruments are fitted with a specially toned buzzer designed to give a soft, pleasant calling signal. The tone and volume of this signal are such that no disturbance is caused to passengers in adjacent cabins.

In engine rooms and at locations where more robust instruments are required, special metal-cased telephones and loud ringing bells are provided.

The three switchboard positions (fig. 27) contain eight panels, six of which carry answering equipment. The two outer panels carry rear apparatus only.

Fig. 31.—Telephone in use in one of the cabin class suites.

The switchboard is constructed in three sections, each having a specially reinforced steel framework, with teak woodwork. All line cables consist of 3/.029 rubber covered conductors, larger than commonly employed in telephone installations. On this account special arrangements were necessary for feeding the cables into the switchboard and terminating them, a suitable run-way being employed along the top of the sections, together with terminal fields giving adequate spacing. The main equipment is thus self-contained and was delivered fully assembled and wired, ready for immediate erection, the work of installation consisting only of bolting the sections in position and connecting the line wires. Duplicate sets of 24 volt storage batteries from which the telephone system is operated are installed in an adjacent room, and the usual form of power panel is provided for charging the cells from the ship's mains.

While the circuit arrangements and apparatus employed are of the simple, reliable and well-tried types found in standard central battery manual exchanges, several of the special features of design and the auxiliary facilities are worthy of notice. Two important factors to be considered in an installation of this kind are, first, space limitation and, secondly, motion of the ship. As already mentioned, the main switchboard equipment is self-contained, the whole of the apparatus being housed within the three sections. For maintenance reasons, however, no sacrifice of access is permissible and it was therefore necessary in planning the internal lay-out to avoid congestion of any kind. The solution to this problem lies in the use of hinged frames, on which all relay equipment at the rear of the switchboard is mounted. These frames may be opened, at once giving access to every component and all internal wiring.

The problem of motion chiefly concerns the use of gravity-restored components which are widely employed in land installations but may not function satisfactorily on board ship. An example is the method of restoring the connecting cords. In standard practice each cord carries a pulley weight which, when the operator withdraws the plug from a jack, returns the cord to its normal position. In place of this device a specially designed arrangement of springs is employed whereby each pair of connecting cords, either at normal or in use, are maintained in their true position relative to the remainder.

Equipment in the face of the switchboard is arranged, in respect of cabin lines, on a "geographical" basis which gives to the operators, who face for'ard, a true picture of the system as a whole. In the six panels these lines appear in deck groups—Sun, Main, "A" and "B"—which in turn are divided into sub-groups. Each sub-group comprises a number of cabins forming a section attended to by specified service staff. These sections are those previously referred to—six on each side, port and starboard, of each deck. Each of these groups of cabins on the switchboard is distinguished by individual coloured designation labels, and associated with each group is the relative line for the service staff, *i.e.*, the corridor telephone. The appropriate corridor line is thus readily identified by the operator when a cabin call is received. Lines to the pantries serving each deck group appear, on the switchboard, at the top of the relative cabin groups, so that the operator on receiving a call for service at once identifies the pantry to which the calling passenger should be connected.

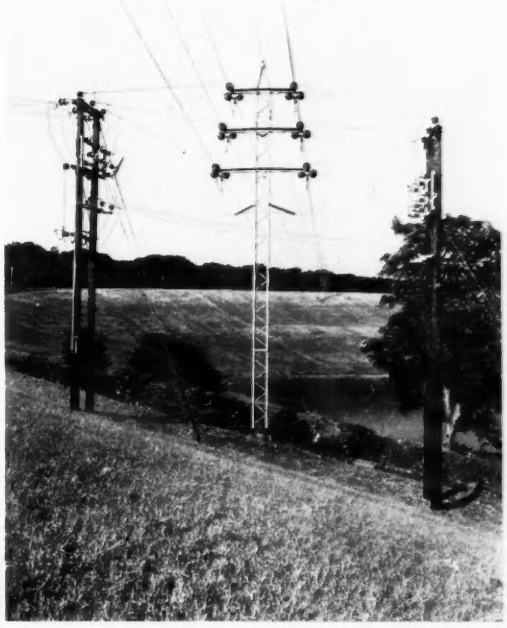
Since three telephones are fitted in close proximity in each pantry, an indicating lamp is associated with each of these instruments in order to denote by visual signal which line is calling. To provide this lamp indication each pantry line is fitted with a "sleeve" relay which operates when a plug is inserted into the relative line jack. Contacts of this relay close the lamp circuit, the lines for which are additional to the speaking pair over which the operator may ring the bell and speak in the usual way.

Lamp calling being employed also for the corridor telephones, similar provision is made for these lines but in a slightly different manner. Although cabins are grouped as described for service purposes, and service staff allotted to each section, port and starboard, on each deck, it may not be necessary at all times for such grouping to be preserved. In the event of waiters and stewards being temporarily allotted duties extending beyond their normal

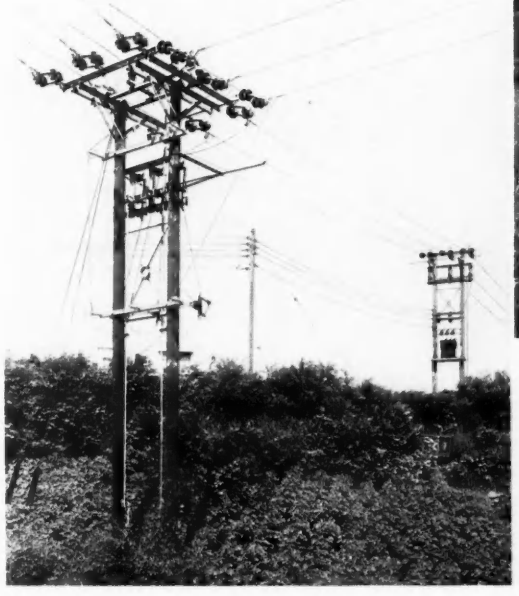
section, provision is required for calling two or more corridor telephones simultaneously so that a reply can be made from that nearest to the point at which the waiter or steward may be. All corridor lines are therefore connected to the switchboard *via* a coupling cabinet (mounted on the bulkhead near the switchboard) at which the "commoning" of these lines can be effected in the simplest possible manner. This coupling cabinet contains auxiliary relays and is equipped with jacks and multiple cords and plugs whereby any number of corridor lines may be commoned to enable the operator to call all telephones so grouped from one of the normal switchboard jacks. When the grouping arrangement is decided upon by the chief steward and the necessary coupling effected at the coupling cabinet, all corresponding line jacks except one in each group on the switchboard are plugged up with red pegs and the remaining jack employed for all calls. Insertion of a plug into this master jack causes all lamps to light on the corridor telephones grouped. An incoming call from any such corridor telephone is similarly answered from this master jack.

Of interest also is the use of the telephone system for public address purposes. Any line can be extended to the band repeating room so that a speech made from a cabin telephone or any other telephone point may be re-diffused by loudspeakers in the public rooms in the same way as gramophone music and radio broadcast programmes.

The Overhead Transmission System of the Wigtownshire Electricity Co., Ltd.



(Right) **The 11,000 volt overhead double circuit ring main of the Wigtownshire Electricity Co., Ltd., showing method of tapping off alternative supplies to Loch Inch Castle, by means of gang-operated isolating links. The supply is taken through a triple pole set of Quenchol fuses.**



(Left) **View near Lochans showing to the right a pole transforming station, tapping off a supply from the Stranraer-Port Patrick overhead line. To the left is a pole switching station with a spur line to South Rhinns Peninsula.**

The Development of Large Radio Transmitting Valves.

By R. Le ROSSIGNOL, B.Sc., F.I.C.,
and E. W. HALL,
Research Staff of The M.O. Valve Co., Ltd., at The G.E.C. Research Laboratories, Wembley, England.

INTRODUCTION.

At the end of the war the largest wireless transmitting valves commercially available were capable of dealing with an input of only 1 kilowatt. Today a considerable number of valves is in use, each of which will handle 500 kilowatts. This increase in power has been due mainly to the progressive demands made by broadcasting. But apart from the question of power, the call for rapid long-distance communication generally, the directive properties of the short-wave beam used in telegraphy, and the increased use of wireless in ships and aeroplanes have each raised specific problems. It is the purpose of this article to review the progress made and describe many of the more interesting problems encountered.

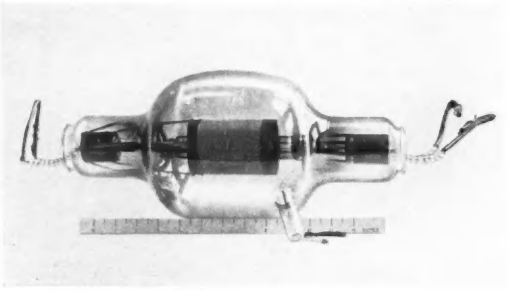


Fig. 1 (a).—MT2 valve.

By way of introduction it will be helpful to study the features of one of the largest valves in use about 1919.

EARLY TYPES.

All valves were similar in construction to that shown in fig. 1, which shows an MT2 valve, one of the largest types of glass valves in common use soon after the war, (*a*) is a photograph and (*b*) constructional details. This type is still in use in small installations or in the low power stages of high power transmitters. The anode dissipation of this valve is 300 watts and, as its construction is typical of all normal glass transmitting valves, it will form a basis for discussing the general design of glass valves and also the fundamentals of valve design.

The bulb is of lead glass 180 mm. diameter, the overall length being 440 mm.; supported from one end is the nickel anode 65 mm. diameter and 100 mm. long. At the other end are the grid and filament systems. The filament is of tungsten wire 250 mm. long and 0.47 mm. diameter, bent into the form of a hairpin. Surrounding this is the grid made of nickel gauze supported on 4 legs, which are fastened to the re-entrant foot tube by a clamp.

One of the major difficulties of a glass valve is that the glass must not reach more than a certain temperature (about 200°C. for the kind of glass employed in this valve), otherwise gas will slowly be evolved from it causing the vacuum to deteriorate, and in the end the grid will lose its control. This means that for a given anode dissipation the glass bulb must be large enough to meet this condition, consequently it will readily be appreciated that there must be a limit to the anode dissipation, unless enormous bulbs are to be employed. Certain hard glasses such as "Pyrex," are now available which can withstand higher temperatures before gassing and thus it is possible to increase the anode dissipation without increase of bulb size ; some of this advantage is, however, neutralized by the fact that these glasses are not so transparent to heat as lead glass. The size of the anode has also to be increased with higher dissipation, otherwise the metal of which it is made will evaporate too rapidly, causing the bulb to blacken, and thus raise its temperature above the safe limit. Another important point is the energy absorbed in the grid. Too great a rise of temperature

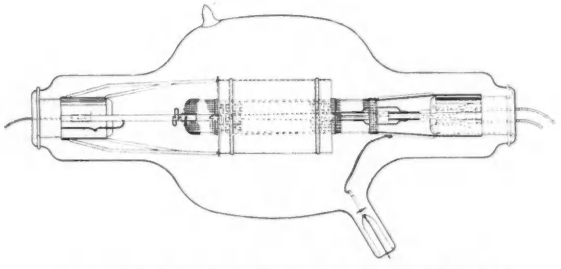


Fig. 1 (b).—Diagram of MT2 valve showing construction.

will cause the grid to become a source of primary electrons, the control of the valve being thus destroyed. Again, the legs of the grid conduct heat to the glass on which it is mounted and if this becomes too hot, gas is liberated with loss of control as already stated.

FILAMENT DESIGN.

The filament (which is the source of electrons), is the most important part of the valve and usually governs its life; for this reason we shall deal with it more fully. For every temperature tungsten has a definite rate of electron emission per unit area and a definite rate of evaporation, the latter rising about twice as fast as the former at normal temperatures. Thus, if a longer life is required at a certain emission, it is necessary to increase the total surface of the filament, and as this is increased, considerably more energy is required to maintain the emission. We have, therefore, to balance the extra power consumed against the longer life and the greater reliability of operation. As other factors are always present which affect the life of the valve, it is useless to increase the filament life beyond a certain value. In practice, transmitting valve lives are considered economic when they are between 3,000—6,000 hours; usually, larger valves are designed to have longer lives than smaller valves. The relationship of emission to life and watts forms one of the most important features of valve design; fig. 2 shows the dependence of these on one another.[1] The values are given for a filament of 1 mm. diameter. Experience has shown that a filament usually burns out when its evaporation has reduced its diameter by 10 per cent. As the rate of evaporation is independent of the diameter, it therefore follows that the life of a filament when run at a definite temperature is proportional to its diameter, or, put in another form, for the same life a thicker filament gives more emission per sq. cm. than a thinner one.

Filament temperature being such an important factor, it is of course necessary to determine this as accurately as possible for each individual valve. Formerly, it was considered sufficient to have a definite number of watts per sq. cm. of filament surface, but as will be seen from fig. 2, the rate of change of filament watts is very slow compared with that of evaporation; again the surfaces of different filaments may differ considerably, so varying the thermal emissivity. Cases have actually occurred in which there was a change of over 15 per cent. Fortunately, there is one easily determined factor varying much faster with temperature than thermal radiation and which (in the case of tungsten) to all intents and purposes, is independent of the surface; this factor is electron emission. As this is the property which is required from the valve, it now becomes possible to determine temperature by the electron emission per sq. cm.

For a number of years this method has been standard, and valves of recent production are marked with the filament voltage which will give a definite number of amperes saturated emission, or more exactly, 90 per cent of that value, since the efficiency of the valve drops off if the last 10 per cent is used. This filament voltage is termed "marked volts." Users have now learnt how important it is to maintain the filament as close as possible to this figure, since by doing so thay have been able practically to double the average life previously obtained for their valves. Of course, if for a particular use the valve requires less emission, it is only necessary to reduce the running voltage as much as possible below marked volts, thereby

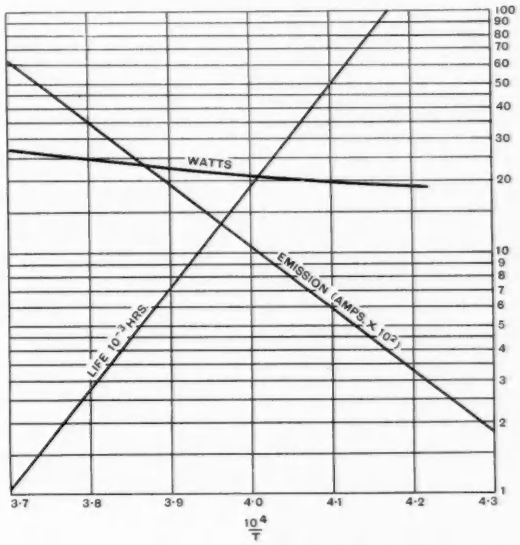


Fig. 2.—Emission and evaporation curves for tungsten.

gaining the advantage of longer life. It might be contended that the necessary filament voltage could be determined at the transmitting station, but experience has shown that this is very difficult when valves are run in parallel as they usually are.

EFFICIENCY AND CHARACTERISTICS.

So far we have not considered the factors which govern the efficiency of the valve, and also, that very important parameter, the magnification or "m" value, as it is usually called. For a detailed treatment the reader may be referred to any text book on the subject; but it will suffice to say here that the efficiency of a valve varies directly as the length of the filament, and is also dependent on the

1.—From determinations made by Dr. A. L. Reimann at The G.E.C. Research Laboratories.

grid filament distance. Usually it may be expressed by the formula :—

$$ia + ig = \frac{kl}{b\beta^2}\left[\frac{Ea + mEg}{1+m}\right]^{\frac{3}{2}}$$

where l = The length of the filament.
b = The radius of the grid.
β^2 = A function dependent on the ratio of grid and filament diameters.
Ea = The anode voltage.
Eg = The grid voltage.
m = Magnification factor.
k = A constant = 1.47×10^{-5}

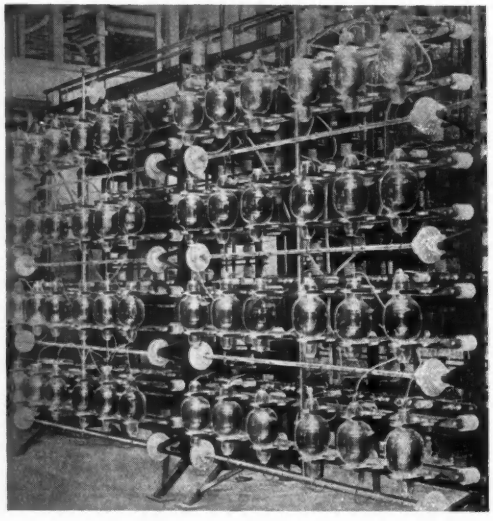


Fig. 3.—Caernarvon transmitter of Marconi's Wireless Telegraph Co., Ltd.

The m of a valve may be expressed as

$$m = \frac{2\pi nb \log \frac{a}{b}}{\log \frac{1}{2\pi ng}}$$

where a = Anode radius.
g = Grid wire radius.
n = Number of grid wires per cm.

From these equations it will be seen that the m value is dependent on the anode-grid clearance and not on the filament-grid clearance, whilst the current depends on the latter, *i.e.*, on the filament-grid clearance, and not on the former, provided that the m values are the same for the various valves under consideration. Usually the efficiency of a valve is measured by its slope or conductance, *i.e.*, $\frac{m}{R}$ where R is the anode impedance. This factor (usually quoted in milliamps per volt) will be found to vary as $\frac{l}{b\beta^2}$ and is most important in designing valves. The above formulae are only true for cylindrical systems and allowances have to be made for a multiplicity of filaments arranged in a circle inside a grid. Provided the distance between filaments is not more than the grid-filament circle distance, the formula gives a useful first approximation when calculating the slope of such a valve. The actual value is about 60 per cent of the theoretical.

INTER-ELECTRODE CAPACITY.

The electrical capacity between the various electrodes is a characteristic which becomes more and more important as the wave length on which the valve has to work decreases. Not only does it affect the lower limit of wave length of the valve but it calls for suitable dimensioning of the grid and anode leads. In the case of glass valves, these may have to be capable of carrying 10–15 amperes at very high frequencies where the depth of penetration of current is only several hundredths of a millimeter, whilst larger cooled anode valves, which will be discussed later, may need to have leads designed to carry several times that amount. Again the inductance of the leads is important at lower

TABLE I.
GLASS TRANSMITTING VALVES.

Type	Anode			Filament			M	Slope ma/volts	Remarks
	Dissipation Watts.	Volts D.C. (max.)	Material	Volts	Amps.	Material			
MT2	300	10000	Nickel	17	15	Tungsten	200	2	Transmitting valve
MT3	40	2000	,,	6	2.2	,,	100	0.3	,, ,,
MT4	100	10000	,,	12.5	6.3	,,	160	1.4	,, ,,
MT5	15	1500	,,	5.8	2.0	,,	40	0.4	,, ,,
MT6	200	10000	,,	15.5	10.0	,,	150	1.2	,, ,,
MT7A	600	10000	Molybdenum	12.5	24.0	,,	80	2.0	,, ,,
MT9	750	10000	,,	16.5	24.0	,,	90	4.5	,, ,,
MT9F	500	5000	,,	17.0	11.5	,,	40	4.4	Short wave transmitting valve
MT10	200	5000	,,	12.5	9.0	,,	200	1.4	,, ,, ,, ,,
MT12	200	2000	,,	12.5	5.5	,,	20	1.3	,, ,, ,, ,,
MT13	800	10000	,,	16.0	22.5	,,	40	2.2	,, ,, ,, ,,
MT4B	80	10000	Nickel	12.5	6.3	,,	60	1.2	Modulator
MT7B	500	10000	Molybdenum	15	10	,,	35	1.2	,,
MT9A	600	10000	,,	16	9	,,	14	1.5	,,
MT9L	800	5000	,,	17	9.2	,,	7.5	3.0	,,
DET1	35	1000	Nickel	6.0	1.9	Thoriated-tungsten	11	1.7	
DET2	150	2500	Molybdenum	12.5	3.0	,,	15	3.0	
DET3	250	3000	,,	15.0	4.0	,,	16	5.3	
DET6	55	1000	,,	10	3.0	,,	32	3.9	

wave lengths, and later it will be shown that by lowering the inductance of the leads considerably lower wave lengths may be reached than is possible with valves of ordinary construction, in spite of the fact that the capacity is slightly increased.

The above considerations are applicable to all valves whether transmitting or not, but of course are of varying importance with the different types.

Reverting to constructional details of glass valves, as mentioned earlier, care has to be taken not to overload the anode and thus produce rapid blackening of the bulb. As the dissipation was increased in valves, a new material, molybdenum, was chosen for anodes which would withstand a higher temperature without undue evaporation. By this means it was possible to increase the anode dissipation to 600 watts in the case of the MT7A valve, which in size is similar to the MT2 valve capable of dissipating only 300 watts. A list of the more important glass valves is given with their special uses (Table 1).

COOLED ANODE VALVES.

It will be seen that of the valves mentioned in Table 1, none has an anode dissipation of more than 800 watts. Since valve efficiency is seldom more than 70 per cent and sometimes not more than 30 per cent, it was necessary to parallel a great number of valves for high outputs. As many as 48 large glass valves were run in parallel at the Marconi station at Caernarvon; fig. 3 is an illustration of the main oscillator bank at this station.

The development next to be described permitted the replacement of these 48 valves by 10 small valves of the new type, and subsequently by a single large valve.

It was obvious that an entirely different valve construction was called for which would allow much higher anode dissipations. Up to now as all the anodes of valves were in a vacuum, they could only be cooled by allowing them to radiate the heat produced. If, however, the anode could be made a part of the envelope of the valve, it could then be placed in water, which would allow a very high surface dissipation. In order to do this it was necessary to make a vacuum tight joint between the anode and the glass part of the envelope. Several types of seal were developed. The most novel one was that of Housekeeper in America who was the first to produce a satisfactory commercial article. He adopted the ingenious method of not necessarily choosing a metal of the same expansion as the glass employed, but instead, made the metal very thin where it joins the glass; in this way the

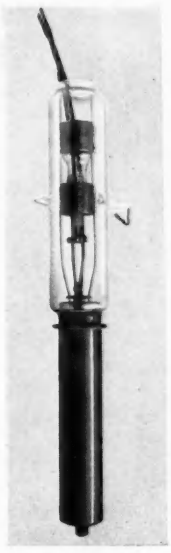


Fig. 4 (a).—Water cooled C.A.T.1 valve with water jacket removed.

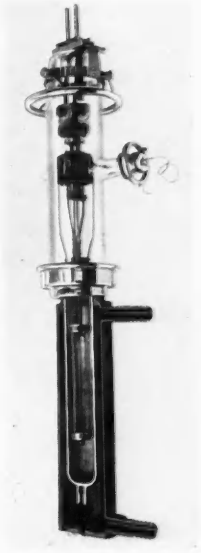


Fig. 4 (c).—Valve with part-sectioned water jacket.

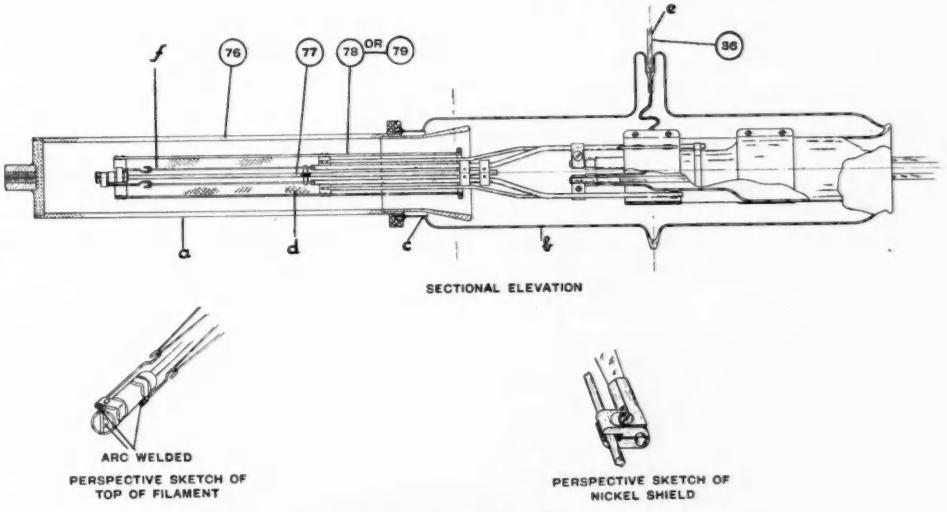


Fig. 4 (b).—Constructional drawing of C.A.T.1 valve.

glass expansion predominates and forces the metal to its own thermal expansion coefficient.

At about the same time an alternative method was developed which was more akin to the much earlier known, but little used, platinum ring joint. Alloys of nickel and iron can be made which have approximately the same coefficient as the glass to be used, and which can be joined directly to glass. Usually the metal is thinly copper plated at the joint, as glass adheres readily to copper and this is facilitated by coating the copper with borax.

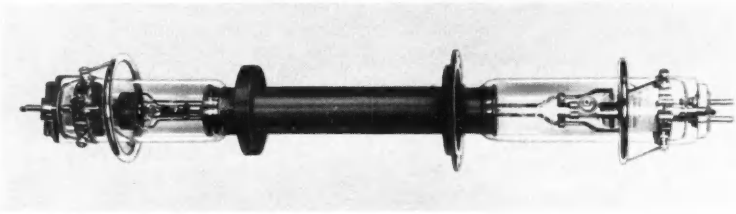


Fig. 5.—C.A.T.2 short wave valve.

The nickel iron is usually turned thin at the edge, in order to compensate for any small difference of expansion. This second method was the one adopted by the M.O. Valve Company in the manufacture of the water-cooled anode valves with which we are concerned here. Still a third alloy, chrome iron, has been employed which functions in the same way as nickel iron. The making of a large glass to metal joint usually inspires awe in the uninitiated, but as a matter of fact, when once the technique has been grasped there is no great difficulty in making such joints. A far more difficult problem encountered at the beginning was to obtain a suitable brazed joint between the nickel iron ring and the copper anode. At the present time the largest glass to metal joint normally made has a diameter of about $5\frac{1}{4}$ inches; while this is certainly not the limit, larger joints have not yet been required.

Earliest Commercial Type.

Fig. 4, shows an early type (the C.A.T.1), of water cooled valve made by the M.O. Valve Company. The anode is of copper 2ins. outside diameter, and $1\frac{3}{4}$ins. internal diameter; inside can be seen the grid which is in the form of a "stocking" of fine tungsten wire. The grid proper is braced by 4 verticals, also of tungsten, the whole being in turn mounted on four molybdenum supports clamped to the glass insulating tube by a nickel iron clamp. Inside is the cathode or filament system comprising two hairpins of tungsten 1.0 mm. in diameter connected in series. In the centre is a molybdenum support for holding the far end of the filament system in place. The leads of this filament system which carries 50 amps. deserve some attention. A number of difficulties were encountered when nickel iron or copper joints of this small size were used, so thimbles of platinum were tried with great success. If the necessarily heavy leads are mounted in position when the thimbles are sealed to the glass legs of the foot tube, cracking of the glass often occurs due to the rapid local cooling. The thimbles are therefore joined to the glass independently (which eases the glass work enormously). After the glass work is finished, a well fitting silver plated copper lead is inserted into the platinum thimble. This is then squeezed onto the lead by the clamp, which also holds the molybdenum conductors on the inside of the valve. Fig. 4b shows the construction, and fig. 4c a part sectioned valve in its jacket. The grid lead is brought through the side of the main glass envelope. A point of interest to engineers is

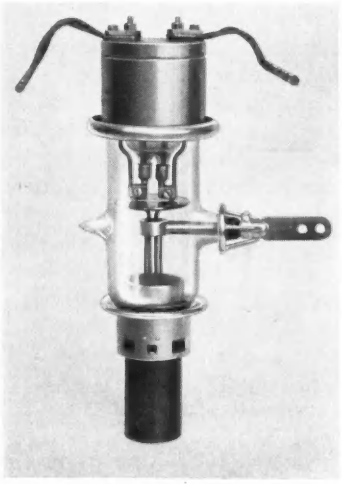


Fig. 6.—C.A.T.15 ultra-short wave valve with water jacket removed.

the loading of the anode, the actual length which is bombarded being 4ins. Thus, with an external diameter of 2ins., there are about 25 sq. inches to dissipate the energy which on test may be over 12 kw., in other words about $\frac{1}{2}$ kW per sq. inch. Later on we shall see that the effect of this abnormally heavy loading brings to light several interesting factors. The C.A.T.1 valve described was the first

to be developed by the M.O. Valve Company and is similar to the earlier American design.[2] It was first employed at the old Daventry 5XX station of the British Broadcasting Company, also at the Rugby station of the G.P.O. and the Marconi wireless station Caernarvon.

Valves are also required for modulating the radio frequency output of a broadcasting station. These are in most respects similar to the C.A.T.1 except that the grid is made more open, thus lowering the magnification or *m* value and also the impedance.

is also a comparatively good conductor. For circuit reasons the grid lead was brought in at the end of the valve remote from the filament leads. Fig. 5 shows the C.A.T.2 valve used for this purpose. It will be noticed that both ends of the anode are glassed.

The C.A.T.15 (fig. 6), of more recent development, has been introduced for oscillating at wavelengths down to 2 meters. Compactness of design and the minimum inter-electrode capacity and inductance have been achieved in a valve of which

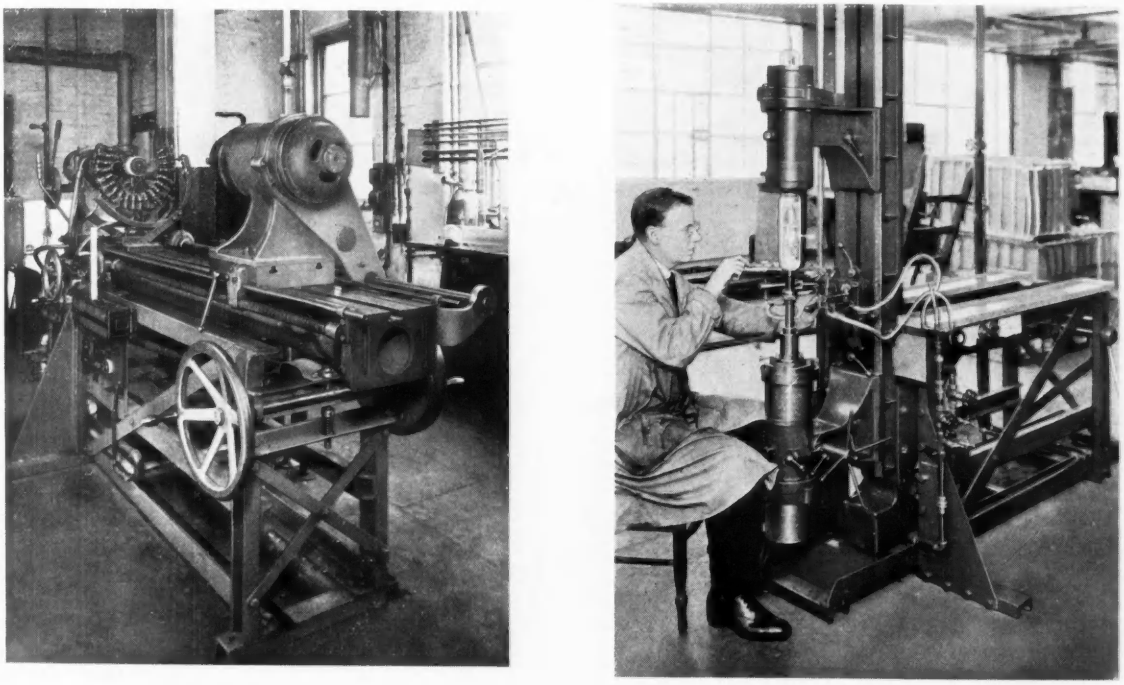


Fig. 7.—Two types of glass lathe used in the construction of large transmitting valves.

Short Wave Valves.

Soon after broadcasting began, a new and highly important development in wireless communications demanded special valves; this was the short wave "beam" of the Marconi Company. As these short waves have a frequency of about 20 megacycles the capacity currents to the various electrodes become high, and so a special design had to be made which could deal with H.F. capacity currents in the grid of the order of 15—20 amperes. This was made possible by using a platinum thimble seal similar to the filament seals described above. Here again platinum is very suitable, as it is not magnetic, and

the overall dimensions are 390 mm. by 176 mm. This valve will handle a maximum input varying from 3.75 kW (5 kV) at 3 metres down to 2 kW (3.5 kV) at 2 metres.

The Glass Lathe.

Up to the present we have not mentioned the special glass working apparatus necessary for making these joints, and for sealing in the electrodes. As the anode is opaque it is impossible to see whether the electrodes are sealed in centrally, so a special "glass lathe" was designed on which the various electrodes could be mounted and centred and then inserted into the anode to be sealed in. This glass lathe has two heads, in accurate axial alignment which can be rotated at equal speeds; these two heads replace the two hands of the glass-blower, who, owing to the size and weights to be handled, would be unable to cope with them. Mounted on

2.—It is interesting to note that although a satisfactory commercial article was first produced in America, earlier attempts had been made. For instance, the M.O. Valve Company at the request of the Marconi Company constructed a water-cooled rectifier as early as 1919, in which a steel tube closed at one end had a platinum mushroom silver soldered onto it, and this in turn was sealed into the glass bulb. The construction employed was the reverse of what is used at present in that the anode was in the centre and the cathode arranged around it. Considerable anode loadings were obtained, but owing to difficulties encountered the experiments were dropped.

the lathe is an array of gas blow-pipes for heating the glass, which can be adjusted and moved along the lathe bed by the glass blower as he wishes. Figs. 7a and 7b show views of the latest types of these lathes, embodying all recent improvements to assist the glass-blower in his work.

of the C.A.T.1 was developed, which is now in use in most of the B.B.C. stations; not only was the valve higher in power than the C.A.T.1, but its characteristics were also improved. These valves are able to operate at an anode voltage of about 10—12 kV, when employed in suitable circuits[3].

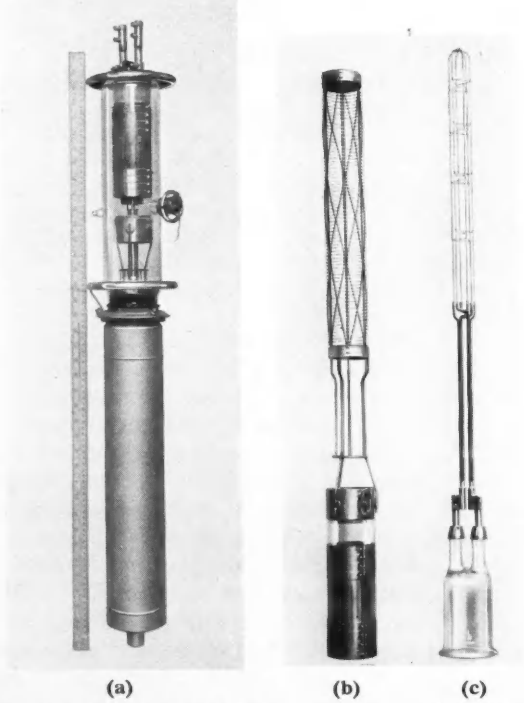
TABLE II.

WATER COOLED ANODE TRANSMITTING VALVES.

Type	Anode		Filament				M	Slope	Remarks
	Dissipation kW	Volts D.C. max.	Volts	Amperes Total	No. of fils. in parallel.	Emission 90% saturated			
CAT.1	5	10000	18—20	50	1	5 amps.	50	5	
CAT.2	5	10000	18—20	50	1	5 ,,	50	5	Short Wave
CAT.4	8	10000	18—20	75	1	10 ,,	45	8	,, ,,
CAT.6	12	12000	18—20	75	2	10 ,,	45	9	
CAT.9	18	15000	18—20	100	2	12 ,,	45	10	Short Wave
CAT.10	50	15000	30	220	3	35 ,,	45	13	
CAT.12A	60—75	18000	30	220	3	35 ,,	10	20	
CAT.14	150	20000	32.5	460	8	100 ,,	45	50	
CAT.15	2.5	5000	11	50	1	4.5 ,,	50	2.5	Ultra short wave
Modulating Valves.									
CAM.1	5	10000	17.5—19	48	1	5 amps.	7	2.8	
CAM.2	5	12000	17	24	2	2 ,,	25	5	
CAM.3	12	12000	17	70	2	3—7,,	6.5	5	
CAM.4	16	15000	20	75	2	10 ,,	10	6.5	

Other Water Cooled Anode Valves.

With the increase in power of broadcasting stations larger valves were required. Another type, the C.A.T.6 of approximately 1½ times the power



(a) (b) (c)

Fig. 8.—(a) C.A.T.10 valve, complete; (b) grid system; (c) filament system.

In Table II is listed a range of water cooled anode valves.

High Power Broadcasting.

About 1930—1931 super power broadcasting stations began to receive active consideration, and although it would have been possible, as was done at Caernarvon with glass valves, to parallel a large number of valves of C.A.T.6 size, it was obvious that the chance of interruption of service would increase with the number of valves employed. A much larger valve, the C.A.T.10, illustrated in figs. 8a, 8b, and 8c, was designed capable of operation at about 15 kV. To this end a new departure in the construction was employed. Up to that time all valves had had their filament systems supported at both ends; this necessitated a guide which was usually sprung to maintain the filament under tension. The design was further complicated by the necessity of an insulator between filament loops, and also in some cases between grid and filament. Such an insulator, situated as it is in the discharge space, when it becomes coated with tungsten by evaporation of the cathode is very liable to cause flash-arcs due to surface discharges. It therefore seemed desirable to construct a filament system which could hang vertically without requiring a guide, and in this way reduce the flash-arc trouble.

The Unsupported Filament.

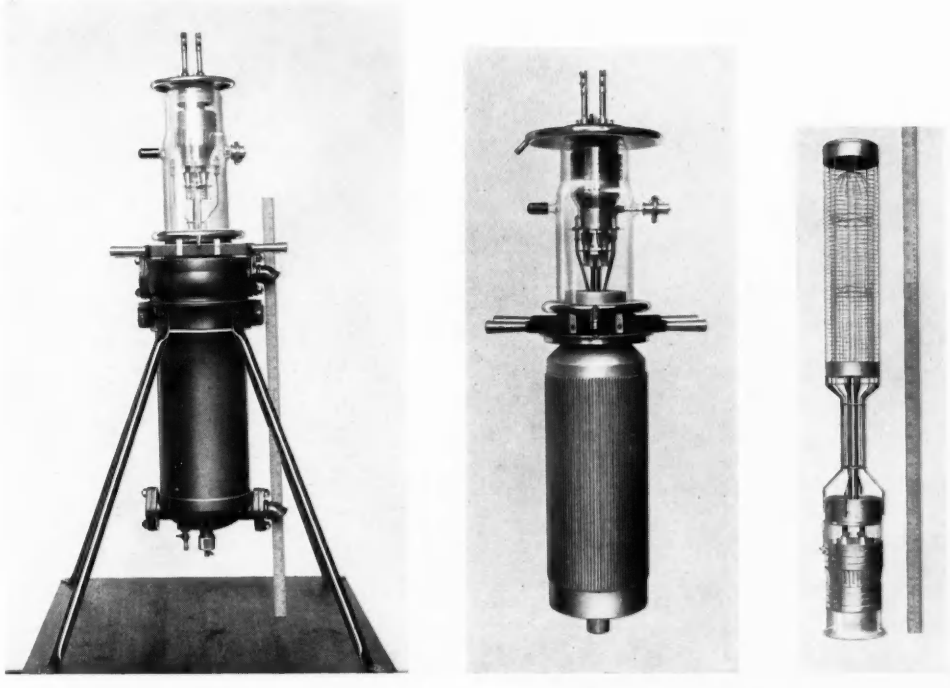
A squirrel cage filament system was therefore

3.—For details of circuits and the effect of high voltage the reader is referred to a paper by B. S. Gossling, J.I.E.E., Vol. 71, p. 460.

made up having six parallel wires joined together at the bottom end by arcing. Alternate wires were connected to each of the two filament leads, see fig. 8c. In order to determine whether such a system was stable inside the grid under the electrostatic forces present during the operating cycle of the valve, a chain system of similar shape and size to the filament system was made up and hung inside a metal tube filled with oil. An E.M.F. was then applied between the chain and tube and the deflection noted for various voltages[4]. Allowing for the dielectric constant of the oil, an accurate estimate of the deflection in an actual valve can be obtained. It must be remembered that the chain system represents the worst possible case, as tungsten is still fairly rigid at its operating temperature. Of course, such a system requires the valve to be mounted truly vertical, but that does not offer any difficulty in a properly designed stand.

The 100 *kW Valve.*

The C.A.T.10 valve has an anode 4ins. diameter and about 20ins. long, the anode-glass seal being 4ins. diameter. The filament system requires 6 kW to heat it, and for this purpose the filament seals must be able to carry over 200 amperes. As a considerable amount of heat, (about 50 watts,) is conducted down each of the leads from the hot filament, it was decided to water cool the filament leads outside the valve up to where the leads pass through the glass. Also, since these seals had to hold the filament central without any extra support, the platinum thimble seal was abandoned and comparatively large nickel iron cones were used. The grid, fig. 8b, which, owing to its length had to be specially rigid, was braced by diagonals between its main verticals; later this bracing was omitted for the reason that owing to unequal heating of the various parts of the grid, strains were set up which caused permanent distortion. To compensate for this, the grid verticals were increased in size.



(a) (b) (c)

Fig. 9.—(a) C.A.T.14 valve in water jacket; (b) without water jacket; (c) filament system.

The construction of this valve constituted an important advance, the power which it was capable of handling being about four times that of the previous largest (the C.A.T.6). Later on a slightly larger edition, the C.A.T.12A, with improved characteristics, was made.

The 500 *kW Valve.*

Owing to the success of this valve and to the increase in the power of broadcasting stations, a much larger valve, the C.A.T.14, was called for, capable of standing up to an anode voltage of 20 kV. Figs. 9a and 9b show the valve with and without

4.—Theoretically, with everything central, the chains should bow out equally, but if the system is slightly out of centre, the whole system is pulled to one side.

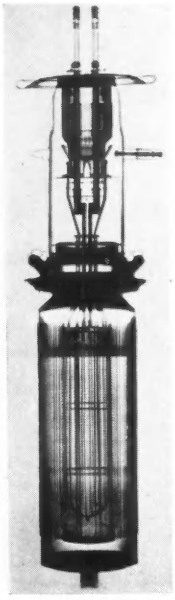


Fig. 10.—Composite X-ray illustration of C.A.T.14 valve.

its jacket, and 9c the inner electrodes. Fig. 10 is a reduced X-ray photo of a valve. The special points of this type are, (i) a squirrel cage filament system of 16 wires, requiring 15 kW with a filament current of 450 amperes. (It is perhaps worth noting that such a filament provides a total emission current of 110 amperes). (ii) Anode diameter 8ins. (iii) anode to glass seal 5¼ins. The anode is ribbed on the outside in order to double its cooling surface, and fits into the jacket with only a small clearance, thus causing the water to flow up between the ribs as well as on the outsides; this anode can readily dissipate over 150 kW. It requires a water flow of 30—40 gallons per minute. Such a valve if worked on telegraphy at an anode voltage of 20 kV could handle an input of 500 kW and give an output of about 350 kW. As used at present in broadcasting stations, it gives a "carrier" output of 50 kW (which means a peak output of 200 kW at 100 per cent modulation) with less than 4 per cent harmonics. Many of these large valves are now in use at Droitwich and various stations in Europe. Despite operation at this voltage, the highest used in broadcasting, these valves have been singularly successful, and their operation has been marked by complete freedom from flash-arcs. Fig. 11 gives characteristic curves for the type.

Anode Loading and Cooling Methods.

At this point we may appropriately discuss the cooling of the anode. As previously mentioned, the loading of the anode may be as much as ½ kW per sq. inch and if this figure is compared with that for other types of apparatus (such as immersion heaters), it will be found that the latter are normally loaded to about $\frac{1}{10}$ of this figure; such heavy loadings may cause serious effects which were not appreciated at the beginning.

For the purpose of cooling valves of the C. A. T. 2 type, oil instead of water, had been adopted to eliminate trouble due to high frequency losses in the insulation of the water system; it was found, however, that the anodes of these valves were eroded so seriously that several anodes were perforated. In order to investigate this effect, one end of a eureka wire was embedded in the surface of the anode at the point of highest loading, forming with it a eureka-copper thermocouple which was used to measure the surface temperature of the anode at various loadings. A surprising result was obtained. It was found that although the temperature of the bulk of the oil did not rise appreciably, the anode temperature rose very rapidly at light loads (0.1 kW per sq. inch), the rise being proportional to the load, see fig. 12, but at a certain point which was dependent on the cooling medium the curve bent sharply, and ran much more horizontal. This point of change of slope corresponded in all the different oils tried with that known as the "first drop" point. In other words, the heat exchange between anode and cooling medium only

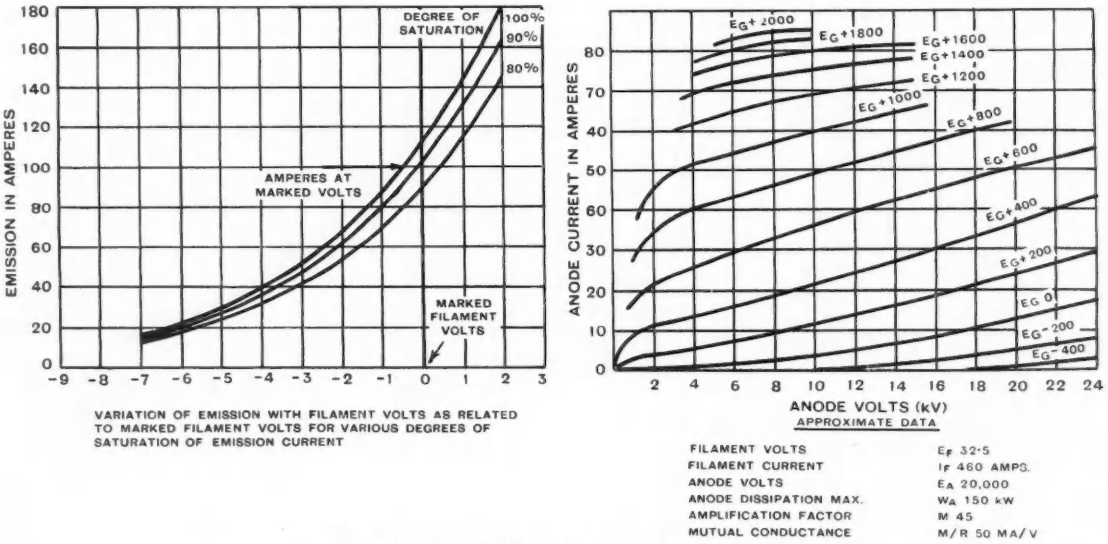


Fig. 11.—Characteristics of C.A.T.14 valve.

becomes really efficient when incipient boiling takes place on the surface of the anode. If an ordinary high class transformer oil is used, the temperature at which this takes place is so high as to cause the valve to evolve gas; if, however, an oil of lower boiling point, such as "kerosene" be used, this point may lie between 140° and 160° Centigrade, at which temperature the vacuum remains unimpaired. Another point has still to be guarded against, namely "sludging." This effect is well known to electrical engineers, in connection with oil cooled transformers. If unsuitable oils are used (especially if oxygen is present), a sludge is formed on the copper conductors. Exactly the same effect takes place with oil-cooled anodes, but with the added effect that when sludge is formed this acts as a lagging, and further raises the anode temperature causing the sludge to "crack," just as oil is "cracked" in refining processes.

This cracking liberates nascent hydrogen, which causes the copper of the anode to become brittle, due to the reduction of the copper oxide in the grain boundaries of the metal, and in the end copper particles become detached.

The actual rate of rise of the first part of the curve can be varied considerably by increasing the rate of flow past the anode, either by increasing the actual quantity of oil flowing through the jacket in unit time, or by restricting the space. Thus in later designs, jackets were made with comparatively small anode jacket clearances (about $\frac{1}{8}$ inch).

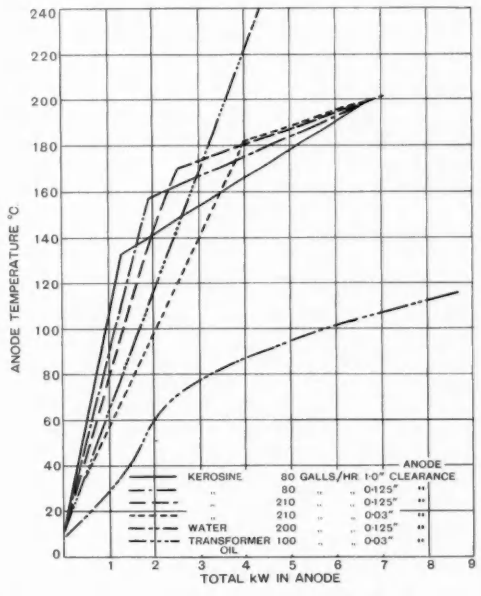

ANODE TEMPERATURE °C
TOTAL kW IN ANODE
ANODE
KEROSINE 80 GALLS/HR 1·0" CLEARANCE
80 " " 0·125" "
210 " " 0·125" "
210 " " 0·03" "
WATER 200 " " 0·125" "
TRANSFORMER OIL 100 " " 0·03" "

Fig. 12.—Temperature of C.A.T.2 anode at various loadings when using different oils and also water.

When water is used as a cooling agent a similar effect is noticed but it is not so marked. The first change in rate of rise is noticed at about 70°C., this corresponds to the point at which the dissolved air is being driven out of the water. After this the rate of rise is slower but at very high loadings (which may be locally as high as 2 kW per sq. inch), the temperature of the anode may reach 140°C.

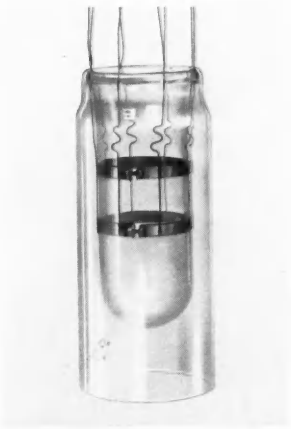


Fig. 13.—Circular grid seal used in short wave valves.

AIR-COOLED ANODE VALVES.

So far we have considered two different methods by which the anode can dissipate its heat (1) by radiation (as in glass valves), (2) liquid cooling. There exists a third method employed for valves of about the same wattages as glass valves. The method is similar to (2) but air is used to cool the anode instead of a liquid; the air circulation being either by convection or by forced draught. This last method is a development of the metal envelope valve made under the trade mark "Catkin," which was in its turn a development of the water cooled valve. Valves with this method of cooling offer certain advantages over ordinary glass valves, due partly to the electrode arrangement and also to the "circular" grid seal (fig. 13) originally developed for metal envelope valves. Air-cooled anode valves, owing to the much lower inductance of the anode and grid leads, allow wave lengths to be reached of the order of $\frac{1}{2}$ to $\frac{1}{3}$ of those possible with normal short wave glass valves. Although casual consideration of the effect on capacity would lead one to expect the anode grid capacity to be considerably higher, in actual practice the difference is not marked. This is due to the elimination of the long anode lead in the normal glass valve; this lead adding to the capacity as well as the inductance. Another advantage possessed by cooled anode valves over glass ones, is the enormous "clean up" property of the surface of the cooled anode, which is able to adsorb large quantities of gas. The anode in a glass valve is unable to do so, owing to its high working temperature. This "clean up" effect allows of the

easier attainment of emission from various "dull emitter" cathodes, and prevents the posioning of these cathodes during life. During the last few years a number of different types employing air cooling have been developed, and a few of these have now passed out of their experimental stage. Table III gives their provisional ratings and fig. 14 illustrates several of the types.

SCREEN GRID VALVES.

Up to the present we have only considered the three electrode transmitting valve, but certain advantages can be obtained if screened grid valves are used. There is much less chance of "back coupling" or reaction, and thus higher gains of amplification per stage can be obtained without employing the difficult neutrodyning method, which in the end leads to instability. Up to the present two screen grid valves have been made of 75 and 400 watt dissipation. These valves were at first made in the normal glass construction, but with the introduction of the air-cooled anode they were redesigned with considerable improvement both in lower limit of wave length and dependability (see Table III).

DULL EMITTER CATHODES.

Only casual mention has been made of cathodes other than pure tungsten. Two other emitting cathodes have been developed during the last 18 years (which is the period under survey). These are the thoriated tungsten, and the oxide coated cathode. The emission of the former is about 10 times, and of the latter 20 or more times that of pure tungsten for the same watts input, with an economical life. At the same time a valve with improved characteristics is attainable.

Thoriated Tungsten Cathode.

This cathode is made by adding about 1 per cent of thorium oxide to the tungsten powder used in the manufacture of tungsten wire. The process was first developed for lamps in about 1912, in order to overcome the brittleness of pure tungsten. If such a wire is used in a valve which is exhausted in the normal way, no special characteristics will be observed. However, if during manufacture the filament is "carbonized" by heating in a hydrocarbon vapour so that it absorbs 0.5 per cent or less of its weight of carbon, it can be made to exhibit a very marked improvement in emission. It is, however, necessary that the valve be pumped specially hard, or that a suitable "getter" (which has the property of "cleaning up" or absorbing any residual or evolved gas), be introduced. As mentioned above, this cathode can have a useful emission of about ten times that of ordinary tungsten. The filament, however, is comparatively brittle, and is also liable to loss of its emission if the valve is subject to overloads which cause gas evolution. Where the weight of the source of filament heating has to be considered or improved characteristics are required, the thoriated tungsten cathode has a great advantage.

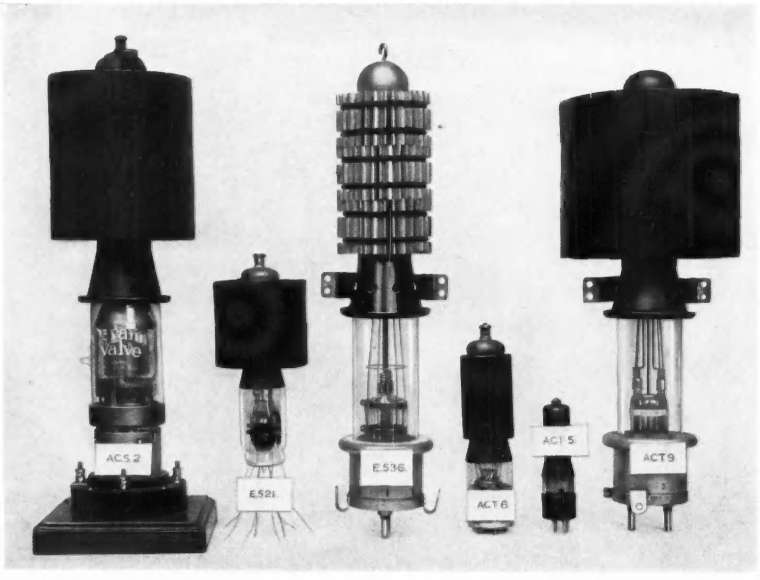


Fig. 14.—Group of air cooled anode (A.C.A.) valves (see Table III). Valves with E numbers are still experimental. The E521 valve is uncapped and shows the multi-wire circular grid seal.

Oxide-coated Cathodes.

These cathodes, first used in receiving valves, depend usually on the emission from a coating composed of barium and strontium oxides on a nickel core (either wire, strip or tube). Up to the present their use in transmitting valves has been limited to 100 watts or less anode capacity and to comparatively low voltages. This emitter is the most recent one and offers a further saving of power over the thoriated tungsten cathode; it is at the same time comparatively robust. A column in Table III shows the cathode materials used in the various types.

inside the bulb, and were in fact very similar to the M.T.2, described on page 176, the grid being omitted.

When the use of cooled anode transmitting valves in larger sizes became general, the development of high powered cooled anode rectifiers followed as a logical step. Since the function of a rectifier is simply to rectify and not control, a theoretical energy conversion efficiency of 100 per cent might be thought possible. This would necessitate the voltage drop in the rectifier being zero. Normal thermionic rectifiers have a very high impedance, but by suitable design this can be considerably

TABLE III.

AIR COOLED ANODE VALVES.

Type	Anode		Filament			M	Slope	Remarks
	Volts (max.)	Dissipation watts	Volts.	Amps.	Material			
ACT9	6000 6000	1000 800*	16—17	22	Tungsten	40	3.5	With forced air cooling. With normal convection cooling. *At reduced input the A.C.T.9 can be operated down to a wave length of 10 metres at 5 kV. 4 metres at 4 kV. 3 metres at 3 kV.
ACT6	1500	75 max.*	10	1.6	Oxide coated	25	5.0	*At lower wave lengths the A.C.T.6 can provisionally be operated under the following conditions :— 4 metres 800 anode volts 10 watts output (appx.) 6 " 800 " " 25 " " " 10 " 1000 " " 65 " " " 20 " 1500 " " 90 " " " and above.
ACT5	1500	15	6	0.6	Oxide coated	40	0.8	
†E521	2500	150	12.5	3.0	Thoriated-tungsten	10—12	3.2	
ACS2	4000	400	15	6.5	"	300	3.4	Screen Grid.
ACS1	2000	75	10	3.0	"	218	2.0	Screen Grid.
†E536	6000	1500	20	24	Tungsten	7	6.5	Modulator. Forced draught cooling.

† Types bearing an E number are still experimental.

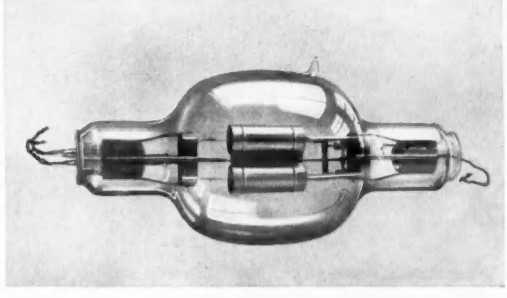


Fig. 15.—MR9 rectifier embodying binocular anode construction.

RECTIFIER VALVES.

Up to the present we have considered only valves containing three or more electrodes; all of these valves can be used to amplify an incoming signal. There is also another type, the rectifier, which occupies a very important part in the equipment of most transmitting stations. In order to obtain high tension direct current either special D.C. machines have to be used or, more usually, high tension alternating currents are rectified by means of a two electrode valve. As with other valves, these at first were of glass with the electrodes

reduced. In order to do this, as stated earlier, the length of the cathode should be as great as possible. There is, however, another important point in designing these rectifiers. When the valve is not conducting, *i.e.*, on the reverse half cycle, a very large voltage difference occurs between the anode and cathode resulting in an electrostatic pull between them. Unless this can be equalized all around it, the filament may be drawn over to the anode causing a short circuit. In normal valves where the cathode is in the form of a hairpin a comparatively strong spring prevents the filament from bowing out too far.

Low-impedance Rectifiers (Design).

However, a design was evolved[5] by which the limbs of the hairpin (if it may still be so called) were separated and each was placed in an anode of its own. The two cathodes were connected by a rigid cross piece and the two anodes placed side by side in one bulb, as in the case of the glass rectifier MR9 (fig. 15).

In the case of water-cooled valves, these anodes form, of course, part of the envelope. The construction was greatly simplified by forming the

5.—British Patent No. 239736 (General Electric Co., Ltd. and A. C. Bartlett.

anodes out of a single large tube, pressed into two parallel cylindrical portions. Fig. 16 is a photograph of such a valve, fig. 16a shows a section of the anode in the central portion in which the each filament is central in its anode there is little tendency for it to be pulled sideways. Thus, a smaller tension is sufficient to keep the filaments central. Fig. 17 gives the characteristic curve

Fig. 16.—C.A.R.2 rectifier embodying binocular anode construction.

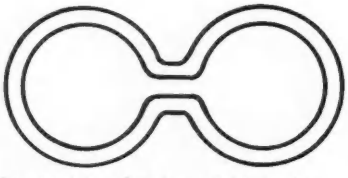


Fig. 16 (a).—Section of binocular anode.

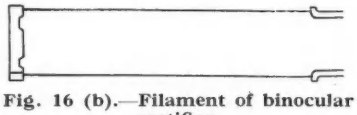


Fig. 16 (b).—Filament of binocular rectifier.

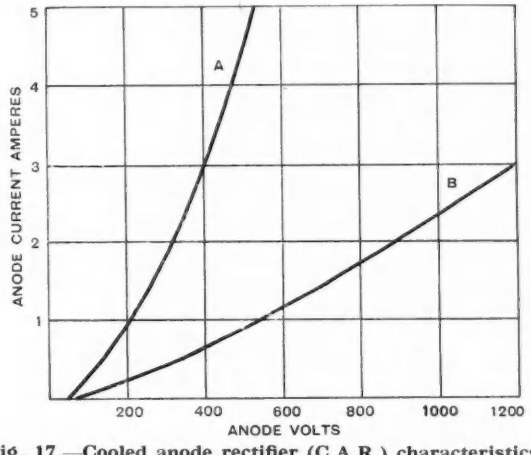


Fig. 17.—Cooled anode rectifier (C.A.R.) characteristics. A = Binocular anode system. B = Cylindrical anode.

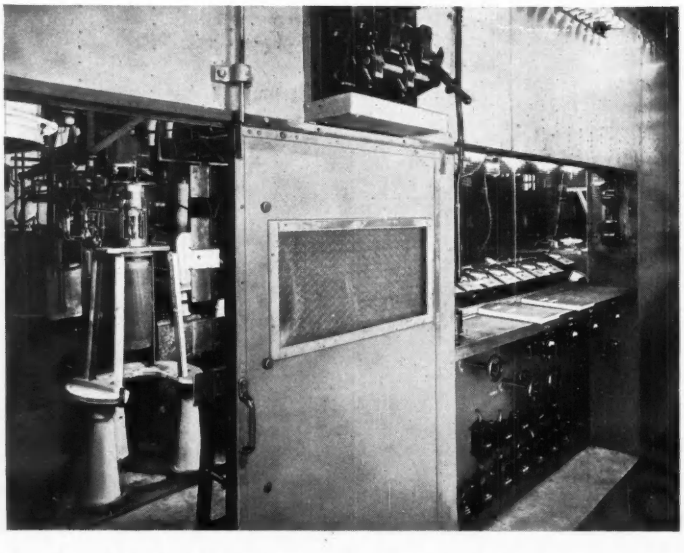


Fig. 18.—Exterior view of modern, fully protected double pump table for exhausting two C.A.T.14 (500 kW) valves simultaneously.

emitting cathode is mounted, and fig. 16b the design of cathode.

By this type of design, a rectifier has been obtained having a considerably lower impedance, and since of such a valve (curve A), while curve B gives that obtained with a rectifier of similar filament wattage but in which a more bunched filament is used.

In Table IV ratings are given of the various

types, their maximum working D.C. voltage, and the current which can be obtained when using either biphase half wave, or three phase half wave. By using a full wave circuit still higher voltages are possible, but as two valves carry the current in series the voltage drop across the unit is doubled.

Rectifiers of these types employing a tungsten cathode have a very useful characteristic, namely that of limiting the current on a short circuit, due to the fact that the cathode, for any given temperature, has a definite emission per sq. cm. and that this emission is practically independent of the voltage across the rectifier.

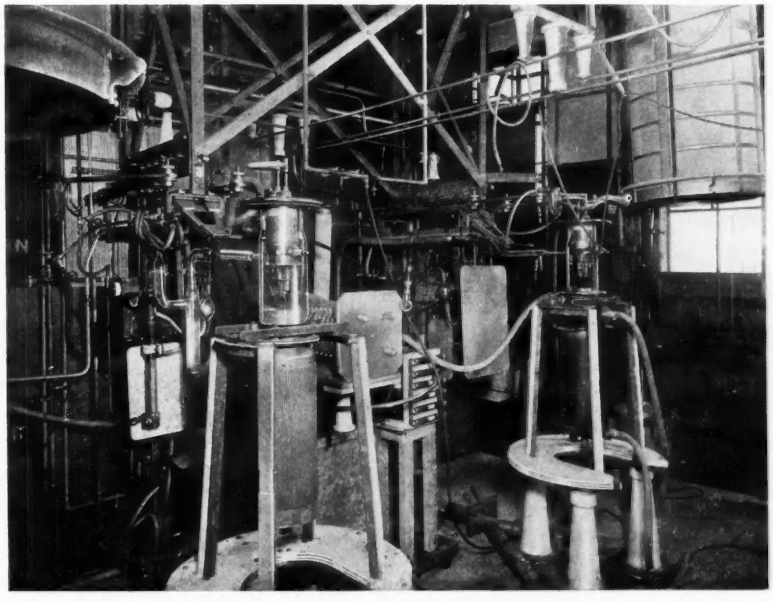


Fig. 19.—Interior view of modern pump table.

Fig. 20.—Pump tables in use at M.O. valve works in 1920.

MERCURY VAPOUR RECTIFIERS.

Until recently, the rectifiers described have been in constant use, but new types containing mercury vapour have been developed, and although their development is progressing rapidly, the vacuum

type is still a very important one, owing to its proved reliability and its short circuit current limiting properties. It is not intended to discuss mercury vapour rectifiers in this article, but it may be mentioned that the cathode can either be oxide-coated, or a mercury pool. As the voltage drop is about 10 and 30 volts respectively and is independent of the current it is readily seen that their efficiency is extremely high.

MANUFACTURE.

The manufacture of these valves would require an article to itself, but it might be of interest to contrast the plant in use 17 years ago with that of the present day. Fig. 20 is an old photograph (about 1920) of the exhausting plant for early glass valves which occupied about one day in pumping.

Fig. 18 is the exterior and fig. 19 the interior view of a modern fully protected installation capable of exhausting two of the largest present day valves simultaneously, an operation which, working night and day, takes a week or more to complete.

TABLE IV.

RECTIFYING VALVES.

Type	Anode		D.C. output from circuit*			Filament			Remarks
	Material	Cooling	Volts	Amps.	Rectifying circuit	Volts	Amps.	Material	
MR2	Nickel	Radiation	10000	0.2	Biphase	17	15	Tungsten	
MR6	,,	,,	10000	0.3	Biphase	15.5	10	,,	
				0.5	3 phase ½ wave				
MR7a	Molybdenum	,,	10000	0.8	Biphase	12.5	24	,,	
				1.2	3 phase ½ wave				
MR9	,,	,,	10000	0.35	Biphase	14	24	,,	"Binocular" Anode
CAR2	Copper	Water	12000	2.0	Biphase	20	50	,,	"Binocular" Anode
				3.3	3 phase ½ wave				
CAR4	,,	,,	12000	4	Biphase	20	75	,,	"Binocular" Anode
				5	3 phase ½ wave				
				10	3 phase double Y				
CAR6	,,	,,	20000	17	3 phase ½ wave	20	120	,,	"Binocular" Anode
				34	3 phase double Y				

* In biphase circuits condenser input to filter.
In 3 phase circuits choke input to filter.

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"Osira" Lighting in a Boiler Works.

The use of "Osira" lighting in industrial undertakings continues to increase. One of the latest installations is in the works of the Beeston Boiler Co., Ltd., of Nottingham. The illustration shows one of the various departments converted to this form of lighting.

Metalclad Switchgear at Cardiff.

By A. M. ANDERSON, A.M.I.E.E.
Witton Engineering Works of The General Electric Co., Ltd.

THE industrial demand for electricity in Cardiff and the surrounding district has shown marked development during the last few years. This increased demand led to a decision by the Cardiff Corporation Electricity Department to distribute at 33 kV in the near future. This practice was followed in the case of the supply required by Guest, Keen, Baldwins Iron & Steel Co., Ltd. Chiefly to meet the requirements of this firm it was decided to install 33 kV metalclad switchgear with a rated breaking capacity of 750,000 kVA at Roath Power Station, which is one of the selected stations of the Central Electricity Board. The contract for this switchgear, the control board and the relay board was entrusted to The General Electric Co., Ltd.

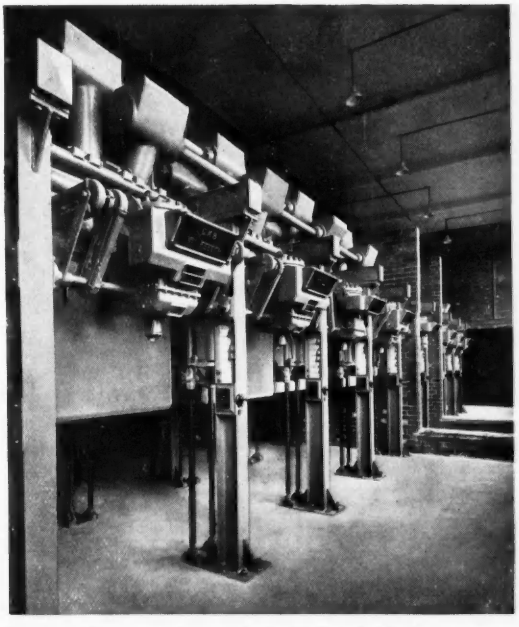


Fig. 1.—General view of 33 kV, 750,000 kVA metalclad switchgear installed at Roath Power Station, Cardiff.

The metalclad switchgear consists of eight units which are housed in a building situated a short distance away from the main group of power station buildings, but adjacent to the grid substation, thus enabling the power cables from the substation to the switch house to be kept as short as possible. The control board and relay board are installed on the switchboard gallery in the generating station.

SWITCHGEAR LAYOUT.

The general layout of the switchgear is shown in figs. 1 and 2. It is arranged in three compartments with brick dividing walls. This degree of separation has been considered advisable in order to ensure maximum safety in the event of fire. The switchgear is divided into two main banks with a bus sectionalizing unit in the centre compartment.

The units control the following :—

2–Outgoing feeders to Guest, Keen, Baldwins Iron & Steel Co., Ltd.
2–15,000 kVA power station transformers.
2–45,000 kVA Central Electricity Board transformers.

In addition to the circuit breakers controlling these feeders a bus sectionalizing breaker and bus coupler breaker are provided. The latter, when closed, joins the front and rear bus bars together. A sectional drawing of a complete unit is given on pages 194 and 195.

TRANSFER BREAKER METHOD OF BUS BAR SELECTION.

The gear is provided with duplicate bus bars, and a single oil circuit breaker on each feeder is arranged to couple either set of bus bars to the feeder cables.

Bus bar selection can be effected only when the circuit breaker is open. Selection is obtained first by isolating the circuit breaker and moving it along the transfer rails until it is in a position directly below the other set of bus bars; from this position it can be raised again to the service position and closed. Fig. 3 shows one of the circuit breakers lowered to its isolated position. This method of bus bar selection is by far the safest from the electrical point of view, due chiefly to the elimination of a chamber which would contain connections from both sets of bars. In addition, the quantity of oil is considerably reduced compared with that type of unit in which oil immersed bus bar selectors are incorporated.

The transfer breaker form of bus bar selection has been criticised on the ground that an undue effort is required to move the weight represented by the circuit breaker and its associated operating mechanism. It has also been contended that this operation occupies too much time. In some designs

these objections have been met by a certain reduction in weight of the moving portion obtained by placing the operating gear on the fixed pedestal framework. The circuit breaker is then connected to the operating gear with removable couplings, which vary in length according to the different service or isolation positions. The disadvantages of this method of coupling are manifest and may lead to faulty operation. Unless couplings of a complicated form are used, the operation of the breaker is only possible at definite set positions.

In the design under consideration a type of coupling is employed for which advantages are claimed over previous methods of bus bar selection. By using this form of coupling the changeover from one set of bars to the other can be effected in less than $6\frac{1}{2}$ minutes without undue effort.

This improvement has been effected by coupling the movable circuit breaker to the fixed operating gear by means of a system of chains arranged in cases which function as radius rods. The coupling is shown in figs. 1, 2 and 3; while the series of diagrams given in fig. 4 illustrate the five different positions normally occupied by the coupling. In all

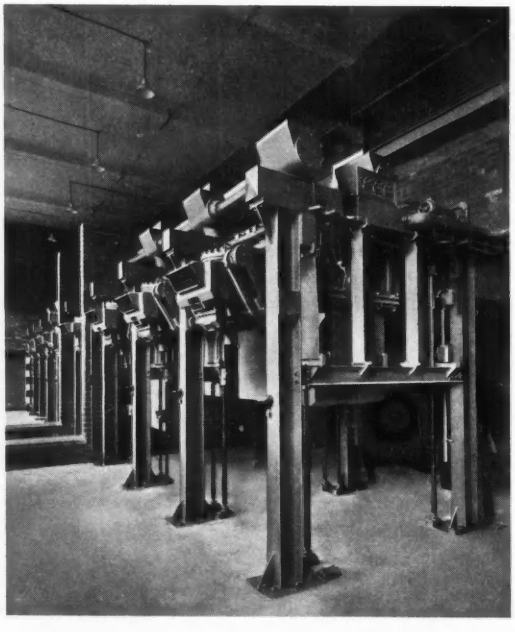


Fig. 2.—End view of the 33 kV metalclad switchboard showing the chain couplings between circuit breaker and operating mechanism.

positions of the circuit breaker it is always coupled to, and can always be operated by, the solenoid actuating mechanism. A circuit breaker is shown in fig. 6 in its fully lowered position ready for withdrawal from the unit. Complete removal of the circuit breaker can be effected quickly by the removal of four bolts from the couplings between the chain cases, as shown in fig 3.

BUS BARS.

A distinctive feature of this metalclad switchboard is the absence of compound filled bus bar chambers, which are replaced by bakelized paper condenser bushings so as to diminish the fire risk. These bushings extend from the compound filled tee joint chamber on one unit to similar chambers on adjacent units. The bushings are enclosed in metal tubes to protect them from mechanical damage.

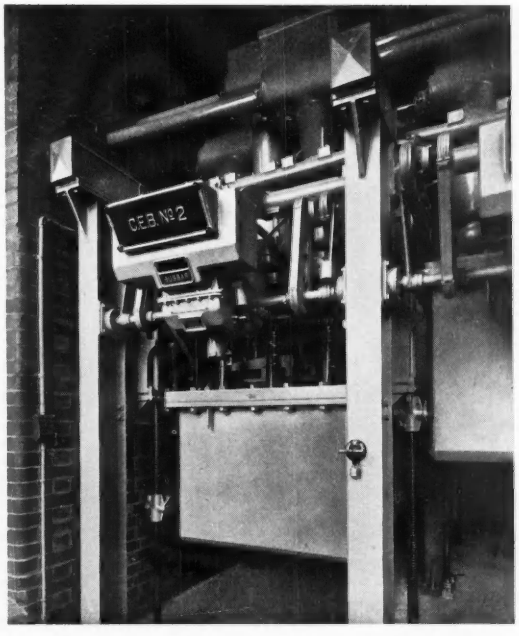


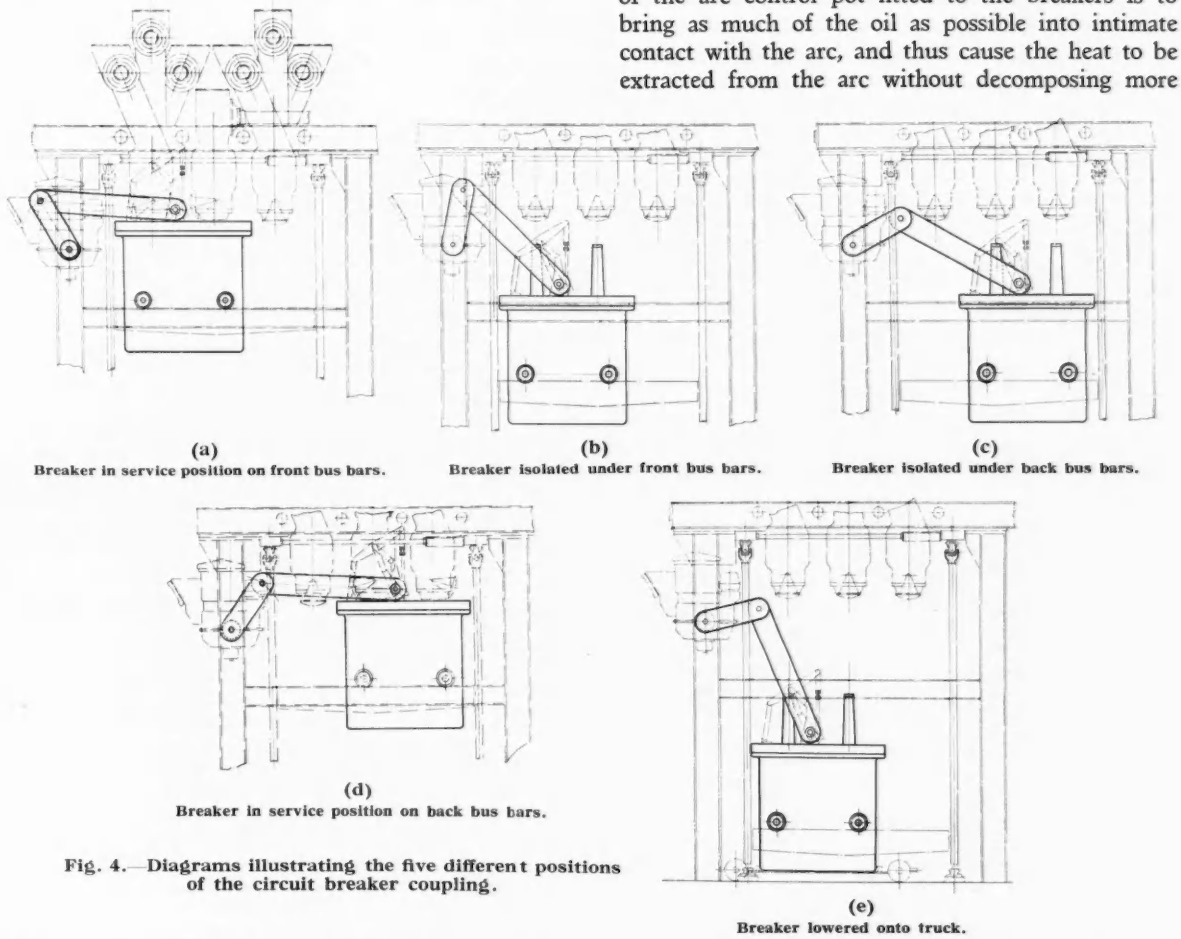
Fig. 3.—One of the metalclad oil circuit breakers lowered to its isolated position.

The section of the bushing which passes through the joint of the tee chamber is bound with wire, and is in metallic contact with the earth foil of the bushing, fig. 7. This enables the outer sheath of the bushing to be earthed, and at the same time permits a compound tight joint to be made by means of a stuffing gland and lead yarn. The use of this form of joint in addition to making a perfect seal, ensures the flexibility necessary to take up any longitudinal movement of the bus bar due to expansion and contraction.

A compound filled tee joint chamber is embodied in order to enable the connection to be made between the spout insulator carrying the isolating sockets and the bus bar itself. It will be observed, however, by reference to figs. 5, 7 and 8, that it has been possible to reduce the quantity of compound to a minimum amount. Owing to the form of the conductors and the use of correctly shaped static shields, it is possible to obtain an even voltage gradient and uniform low stress throughout the tee joint chamber, without providing large thicknesses of compound. This reduction of compound effects

a considerable saving in weight. Moreover, due to the ease with which the heat generated can be dissipated, a much larger ampere capacity is possible for a given temperature rise than was obtainable with older forms of metalclad switchgear which incorporated compound filled bus bar chambers of considerably greater dimensions.

A feature of the insulation of condenser type bus bars is the readiness with which it is possible to determine the electrical efficiency of the insulation, by subjecting it to a watt loss test using a Schering Bridge. It will be appreciated that this method of testing could only be applied with extreme difficulty to compound filled bus bar chambers.



(a) Breaker in service position on front bus bars.

(b) Breaker isolated under front bus bars.

(c) Breaker isolated under back bus bars.

(d) Breaker in service position on back bus bars.

(e) Breaker lowered onto truck.

Fig. 4.—Diagrams illustrating the five different positions of the circuit breaker coupling.

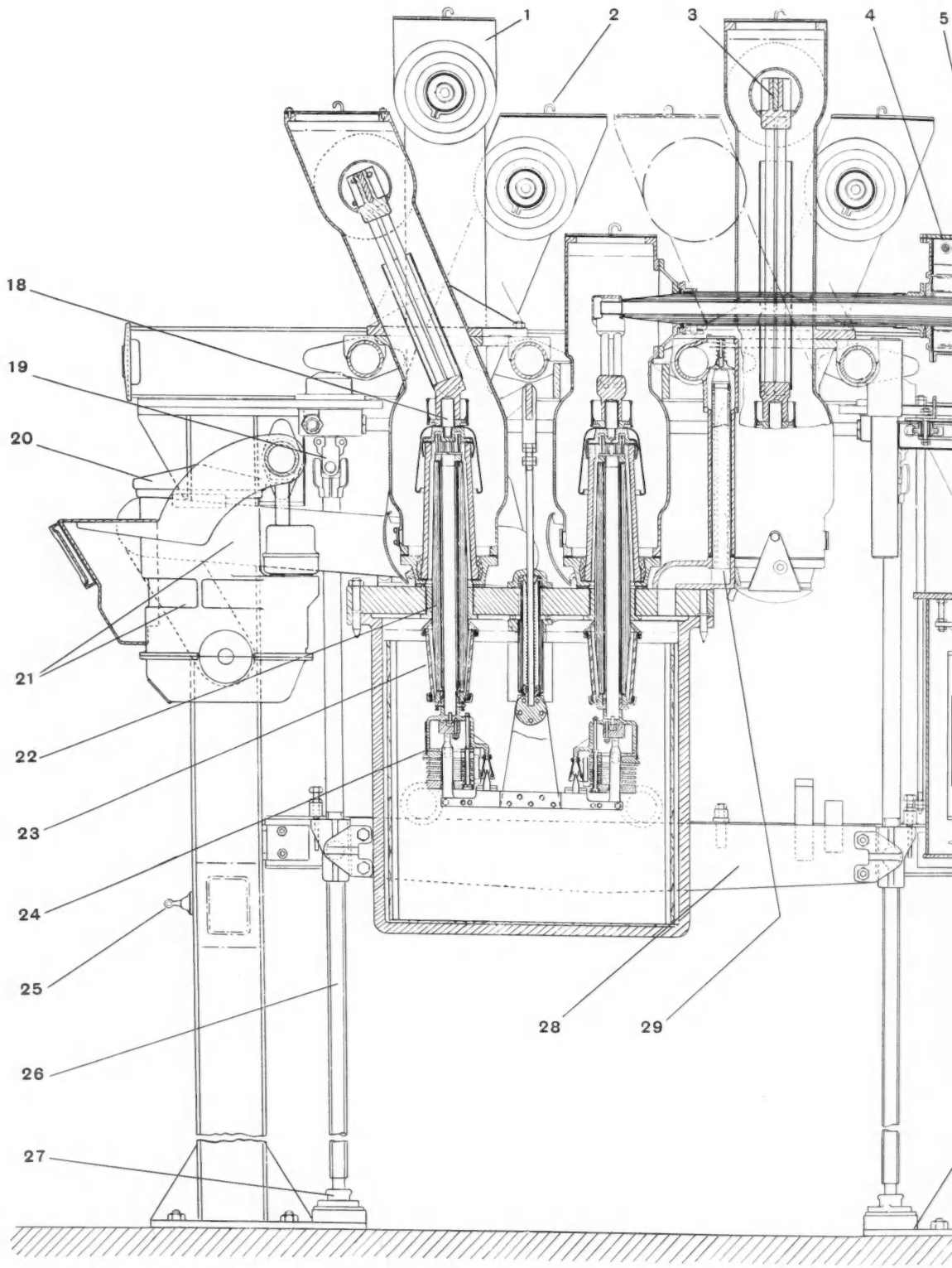
OIL CIRCUIT BREAKER.

Each oil circuit breaker is electrically operated by means of a solenoid, and is constructed in accordance with standard G.E.C. practice. The top cover consists of a single rolled steel plate supporting the operating linkwork. The oil circuit breaker tank is made entirely from rolled steel plate and is equipped with steel interphase barriers which serve also to reinforce the tank. The advantage obtained by this construction is that each phase of the circuit breaker is contained in a separate compartment in the tank. All the breaker bearings are fitted with self-lubricating bushes and stainless steel spindles.

The moving contacts are carried by steel rods, from which they are insulated by means of "Panilax" paper boards. The steel rods are shrouded by bakelized paper tubes.

The form of arc control incorporated is the result of considerable investigation. The object of the arc control pot fitted to the breakers is to bring as much of the oil as possible into intimate contact with the arc, and thus cause the heat to be extracted from the arc without decomposing more than a minimum of oil into free carbon and gas, both of which are determining causes of breakdown. By causing the arc to act upon a large oil surface, the heat is absorbed not only by reason of the specific heat of the oil, but also because of the formation of oil vapour which almost immediately re-condenses into liquid.

The arc control pot consists of a chamber surrounding the fixed arc contacts. A stack of plates made from a mechanically strong insulating material is fixed to the underside of the pot and when saturated with oil the plates possess the necessary resistance to arc erosion. The design of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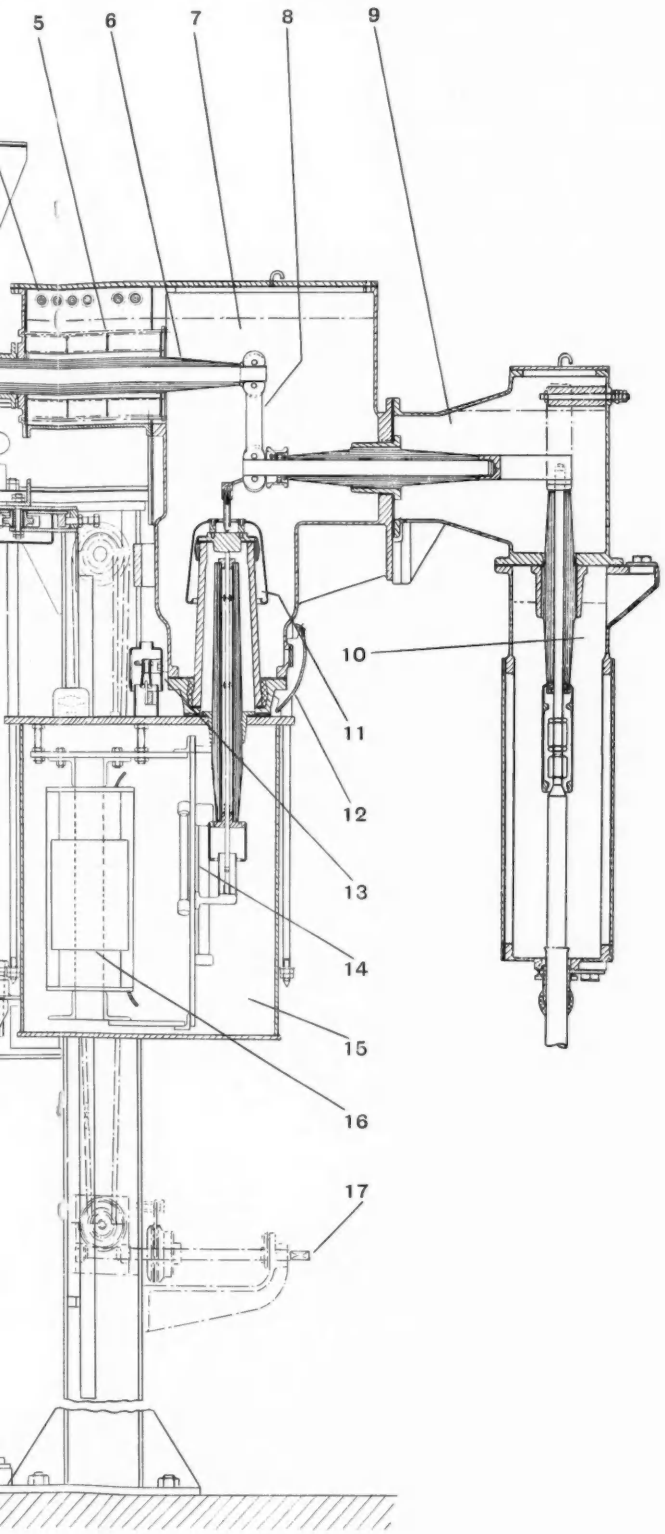


KEY TO NUMBERS ON DIAGRAM.

1. Bus Bar Tee-off Chambers.
2. Air Vent.
3. Bus Bar Tee Joint.
4. Current Transformer Secondary Terminals.
5. Current Transformers.
6. Current Transformer Primary.
7. Current Transformer Chamber.
8. Detachable Connection.
9. Cable Link Chamber.
10. Cable Box.
11. Stress Shield on Potential Transformer Receptacle.
12. Safety Shutter on Potential Transformer Receptacle.
13. Potential Transformer Secondary Terminals.
14. Potential Transformer Fuse.
15. Potential Transformer Chamber.
16. Potential Transformer Core and Windings.
17. Raising and Lowering Gear for Potential Transformer.
18. Plug Receptacle Block.
19. Universal Joints on Hoist Screw.
20. Operating Solenoid.
21. Operating Gear Cases.
22. Breaker Terminal.
23. Breaker Arc Shield.
24. Explosion Pot.
25. Hoist Gear Operating Handle.
26. Hoist Screw.
27. Hoist Screw Bearing.
28. Traversing Rail.
29. Breaker Gas Vent.

Fig. 5.—Sectional drawing through one of the eight 33 kV metal-clad switchgear units supplied to Cardiff Corporation Electricity Department. Breaking capacity, 750,000 kVA.

these pots allows for the very large internal peak pressures which may be obtained.

The moving arc contact enters the pot through a rectangular passage formed by openings cut in the plates, the clearance in these openings being reduced to a minimum so that when the breaker is closed the arc contacts are virtually sealed inside the enclosure. The openings in all the plates, with the exception of the lowest, are shaped to form an oil reservoir at one side of the passage. Each alternate plate is also shaped to provide an outlet from the enclosure at the side of the moving contact remote from the reservoir. Thus, as the contact descends through the passage the side outlets are uncovered in sequence.

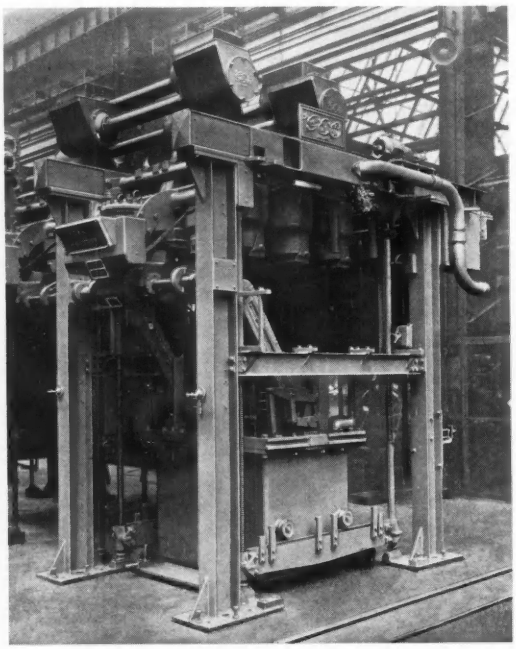


Fig. 6.—A circuit breaker shown in its fully lowered position and ready for withdrawal from the unit on a trolley. View taken during construction.

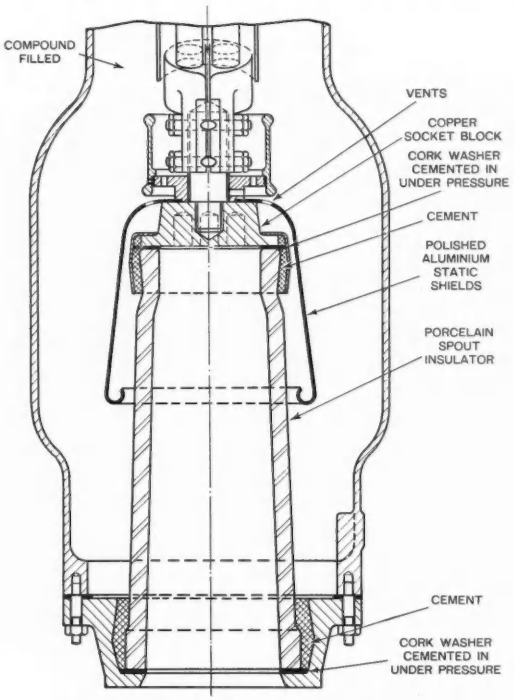


Fig. 8.—Section through spout housing.

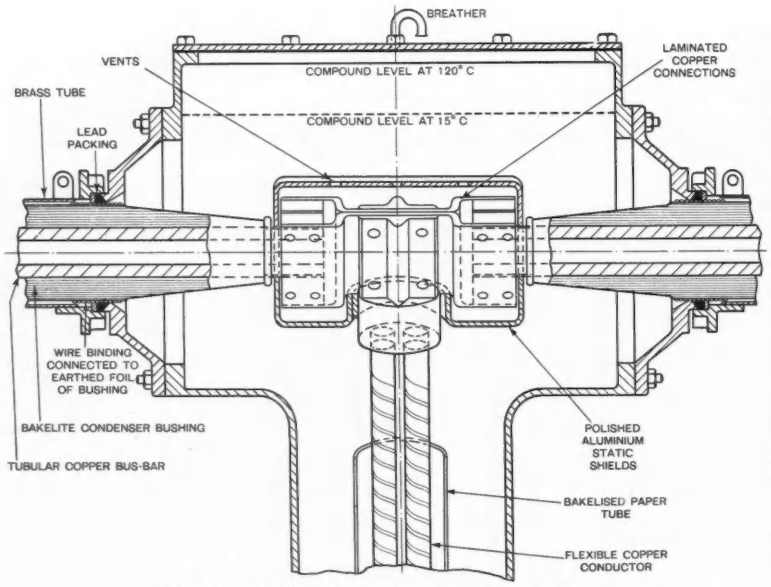


Fig. 7.—Section through tee joint chamber.

When the contacts begin to part, an arc is struck in the space above the plates causing an instantaneous generation of gas under high pressure which cannot escape until the contact has descended sufficiently to uncover the first outlet. The uncovering of the first outlet permits a rapid stream of liquid oil to be ejected across the arc giving a high pressure cross blast; at the same time a further stream descends in an axial direction through the length of the arc. As each succeeding outlet is uncovered a fresh jet of oil is forced across the arc with the result that it is split up and brought into contact with a large surface of oil. This facilitates the extraction of heat from the arc and causes effective de-ionization and rapid arc extinction.

The main fixed contacts are

mounted on the side of the arc control pots; they may be seen in fig. 9.

POTENTIAL AND CURRENT TRANSFORMERS.

The potential transformer, figs. 5 and 10, is arranged in a most accessible position so as to facilitate inspection and maintenance. In addition, inspection of the potential transformer may be carried out while the remainder of the unit is on load. It is mounted immediately at the rear of the circuit breaker and equipped with self-contained manually operated raising and lowering gear consisting of chains which are attached to the transformer tank. This method of attachment renders it impossible to lower the tank and leave the transformer plugged in, or to raise the transformer while live metal is exposed. A considerable space is provided between the transformer and the main cable sealing chamber.

The current transformers are housed immediately above the potential transformer. They are so mounted that it is only necessary to disconnect one connection to enable them to be removed from their housings; moreover, it is not necessary to interfere in any way with the high tension insulators. The current transformer chambers were filled with "Penetrol" after the gear was erected on site.

PHASE ISOLATION.

It should be emphasized that it is impossible for an interphase fault to occur on any part of the unit, as the phases are either in entirely separate chambers or have earthed metal interphase barriers interposed. The separation is carried right through to the cables, as will be seen by the cable box phase barriers in fig. 10.

CONTROL BOARD.

The main control board, fig. 11, is built up of steel plate cubicles with double doors giving access to the back. A distinctive feature in the design of the board is the use of 4-inch dial miniature indicating instruments (except on the transformer tap change panel). These instruments are mounted flush with the panel surfaces and, according to the circuits controlled, indicate amperes, megawatts, megavars and power factor. It will be realized that in a large station with a number of circuits to be controlled from a central point, the use of instruments having a small diameter, greatly reduces the length of the control board and effects a considerable saving in floor space. Thus, with a compact arrangement of control gear an increased efficiency in operation is obtained, as the operating engineer can exercise a closer degree of supervision with less effort and visualize at a glance what is happening over the entire system.

A mimic diagram representing the complete system under control is arranged at the top of the board. All the outgoing feeders are indicated by means of arrows and the oil circuit breakers by

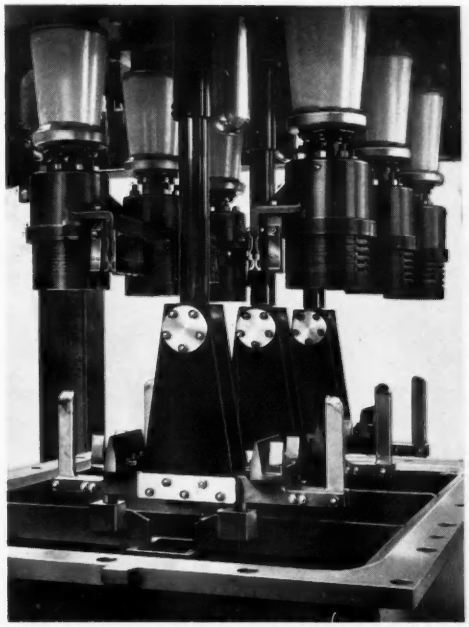


Fig. 9.—Arc control pots and oil circuit breaker contacts. The view shows the arcing contacts after successfully rupturing more than 1,000,000 kVA.

circles. In addition, the diagram automatically shows by colour illumination the state of all the circuits, and also, whether the oil circuit breakers

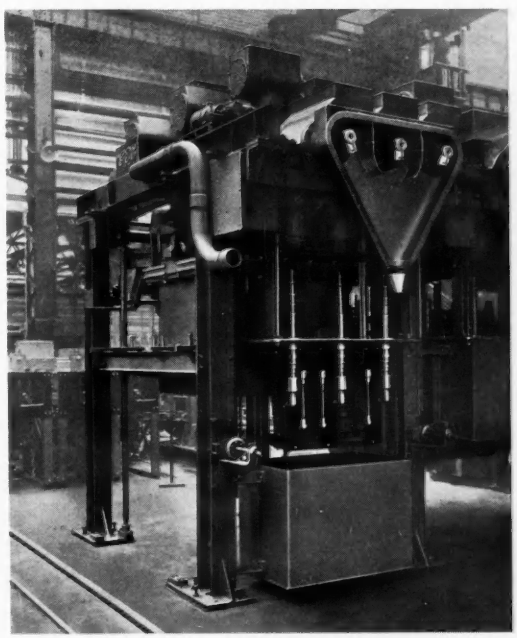


Fig. 10.—Rear view of 33 kV metalclad unit during construction in the works, showing the potential transformer and the cable dividing box with the cover removed.

have been operated intentionally or by the functioning of the protective gear due to faults on the system. Each circuit with its various components is easily distinguished, as all the components are arranged on the board vertically in line.

The use of a miniature indicating type of control board necessitated a radical change in the design of the mimic diagram from that usually employed by the G.E.C. in order to obtain a compact arrangement of diagram. In the new design, the semaphore discs which are usually placed in the mimic diagram representing oil circuit breakers and isolating links have been dispensed with, as well as all indicating lamps showing the state of the circuit which were arranged near the breaker control switches. In their place, a group of seven pigmy lamps is used

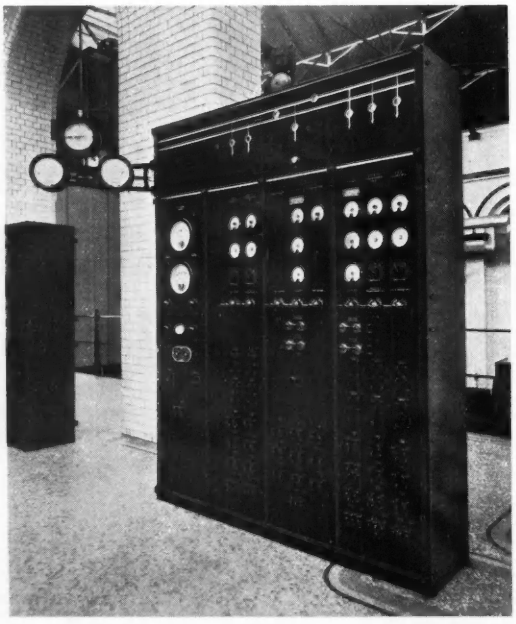


Fig. 11.—Miniature instrument type of control board. On the extreme left hand panel is mounted the standard transformer tap change control equipment.

for the feeders, three for the bus section oil circuit breaker and two for the bus coupler circuit breaker, all groups being incorporated in the mimic diagram itself.

With this latest design of mimic diagram the main metalclad bus bars are represented by two chromium plated metal strips extending the whole length of the board with the lamp groups situated immediately at the rear of the front panels and indicating in colour form as follows :—

Feeder and Bus Section Oil Circuit Breakers (Indication with Three Lamps).

(*a*) Red with breaker closed.
(*b*) Green with breaker open.
(*c*) White when breaker has tripped automatically on a fault ; and at the same time an alarm bell rings.

Bus Coupler Oil Circuit Breaker (Indication with Two Lamps).

(*a*) Red with breaker closed.
(*b*) Green with breaker open.

Feeder Circuit Lines.

(*a*) With the circuit connected to the top bar (front bus of switchgear), the complete line is shown in red when the circuit breaker is plugged in the service position.
(*b*) With the circuit connected to the lower bar (rear bus), the line to this bar only is shown in red with the circuit breaker in the service position, and the continuation of the line between the two bars is then green.
(*c*) With the oil circuit breaker withdrawn for inspection the complete line is shown in green.

A lamp indicator is also supplied to show that the tripping circuit is energized.

The oil circuit breaker control switches are

Fig. 12.—Relay and control boards in the power station.

similar in design to those supplied on standard G.E.C. control boards. In addition to the usual contacts, however, auxiliary contacts are embodied on the switches which operate the white lamp and alarm bell when an oil circuit breaker is tripped due to a fault, while a patented sequence device is supplied to prevent a controller being closed twice in succession

without first moving the handle to the trip position. The controllers are spring loaded to cause them to return to the neutral position after being operated.

The synchronizing voltmeters and synchroscope are mounted on a swing bracket attached to the left hand end of the board. All the fuses in the small wiring circuits are arranged in accessible places at the bottom of the panels as shown in fig. 11.

RELAY BOARD AND PROTECTION.

When the control of switchgear is carried out from a board of restricted dimensions fitted with miniature indicating instruments, it is not desirable that other instruments such as protective relays or metering equipment should be accommodated on the front of the board. These relays are generally of the projecting pattern and are considerably larger than the indicating instruments; moreover, they usually differ greatly in size among themselves according to the type of protection. It will be realized, therefore, that the mounting of the protective relays on the control board would necessitate not only an increase in the size of the board but also would entirely spoil its appearance. In consequence, the protective relays used in connection with the metalclad switchgear are accommodated on a separate relay board. This leaves the control board entirely free of instruments not actually required by the control engineer when performing switching operations.

The close proximity of the relay board to the control board is seen in fig. 12. Both boards are interconnected with each other by small wire cables in conduit. The relay board is constructed in a similar manner to the control board and lines up with it. It is divided into three main panels, the equipment and auxiliary apparatus contained on the centre panel being the property of the Central Electricity Board. The protective relays on this panel are for each of the C.E.B. transformer feeder lines and consist of (1) two D.P. overload relays with restricted earth leakage protection, the overload time settings being from 0 to 2 seconds and leakage fault settings from 20 to 100 per cent of full load; and (2) two separate unrestricted earth leakage relays.

Relays are mounted on each of the two outside panels for the protection of one feeder to Guest, Keen, Baldwins Iron & Steel Co., Ltd., and one of the power station transformer feeders. For the protection of all the four feeders the McColl circulating current system[1] employing McColl biassed beam relays is used, with triple pole overload as a back-up protection. In addition, the power station transformers are fitted with Buchholz protective relays actuated by gas pressure which may be produced in the transformers owing to a fault. For minor faults the one pair of contacts of a Buchholz relay complete a circuit and indicate the first symptoms of a fault by means of a red lamp located on the control board. If a transformer becomes dangerously overloaded and a considerable number of large gas bubbles are formed, the second pair of relay contacts close and trip the oil circuit breaker before any damage is caused.

On the right hand panel of the relay board an additional triple pole overload relay is mounted for the protection of the bus section unit. No protection is provided on the bus coupler oil circuit breaker. All the protective relays are operated from current transformers mounted in the metalclad switchgear, separate transformers being supplied for the instruments, and where metering is required, two extra transformers are used.

OIL CIRCUIT BREAKER RUPTURING CAPACITY TESTS.

The theory of arc interruption and the question of guaranteed rupturing capacity has for some years received considerable attention. It is therefore of interest to give the results of tests which have been carried out on the metalclad breakers employed in this scheme to demonstrate the efficiency of the particular form of arc quenching devices used.

The rupturing capacity tests which are outlined below, comprised a B-3-MB-3-MB duty cycle[2] at approximately 100 per cent rating of the circuit breaker. These tests were proceeded by others at 10 per cent, 30 per cent and 60 per cent capacity, but the lower capacity tests are only reproduced here in tabular form in table 1. The initial line voltages on the three parts of the tests were 38.5, 37.5 and 37.3 kV.

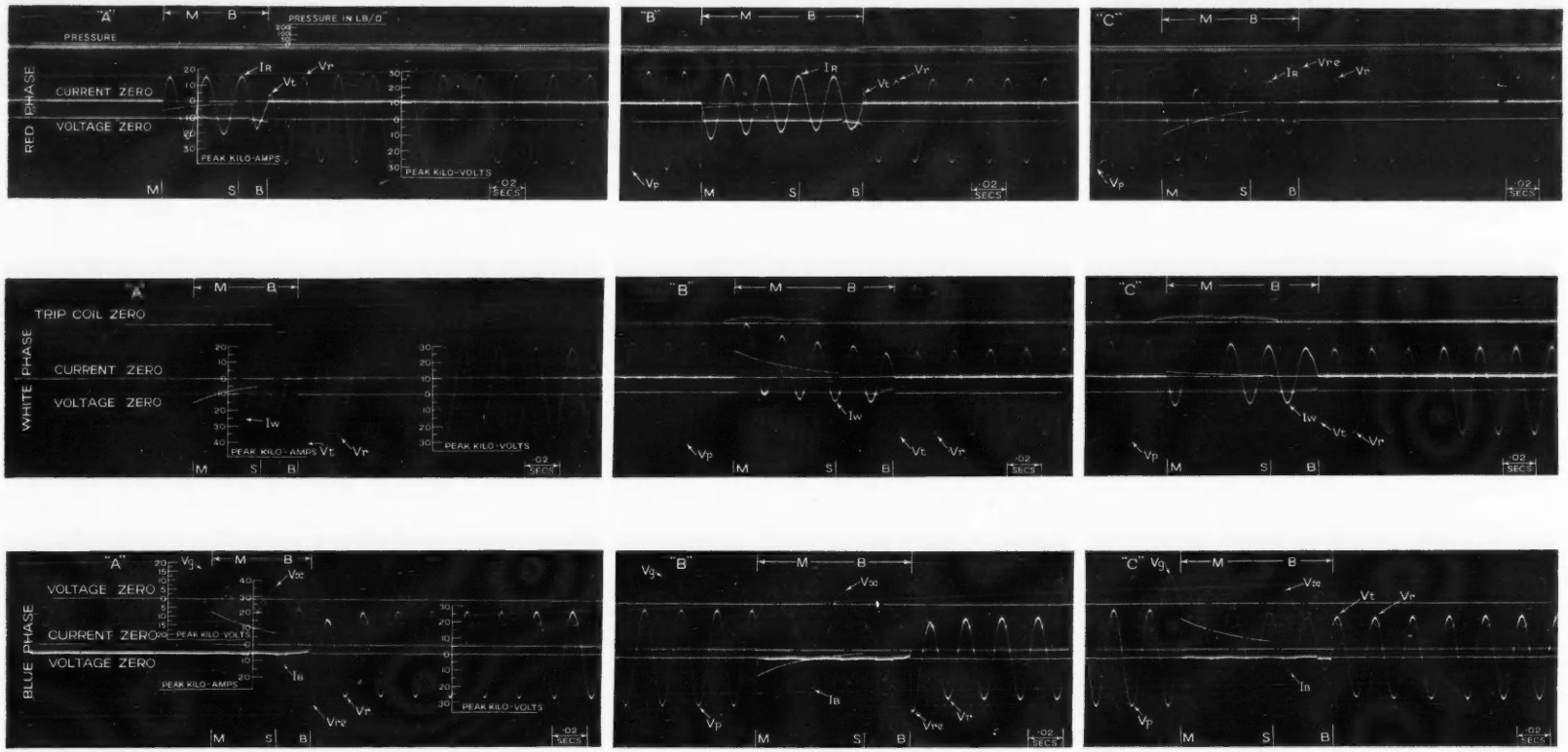
On part "A" of the test, the circuit breaker cleared a short circuit current of 13,500 *R.M.S.* amperes at a recovery voltage of 97 per cent of the rated voltage. The power broken was thus 750,000 kVA, and the corresponding value based on the rated voltage was 775,000 kVA. The maximum time of arc duration which occurred on the white phase was 2.09 half cycles, the corresponding total arc length being 2.9 inches.

On part "B" of the test, the circuit breaker closed on to a current of 33,000 peak amperes and cleared a short circuit current of 12,400 *R.M.S.* amperes. The recovery voltage was 92.5 per cent of the rated voltage, and the power broken 655,000 kVA. Based on the rated voltage, the corresponding value of kVA broken was 709,000. The maximum time of arc duration on this part of the test was 3.84 half cycles, the corresponding arc length being 3.4 inches.

On part "C" of the test, which was a further make-break duty, the circuit breaker closed on to a

1.—G.E.C. Journal, Vol. V, No. 4, p. 227.

2.—In these symbols B signifies "Break circuit," M signifies "Make circuit," and 3, an interval of 3 minutes.



KEY TO SYMBOLS ON OSCILLOGRAMS.

Vg Generator Voltage.
Vp Phase Voltage Across Poles of Test Piece.
I_R Short Circuit Current in Red Phase.
I_W Short Circuit Current in White Phase.
I_B Short Circuit Current in Blue Phase.
Vx Voltage Across Reactors and Resistors.
S Arcing Contacts Separate.
B Instant of Break.
M-B Duration of Short Circuit.
S-B Duration of Arc.
Vt Restriking Transient Voltage.
Vr Recovery Voltage at Final Break.
Vre Recovery Voltage at Break.

Fig. 13.—Reproduction of oscillograms of full load test on the three phases of one of the 33 kV, 750,000 kVA metalclad oil circuit breakers.

short circuit current of 36,000 peak amperes, and cleared a current of 12,900 *R.M.S.* amperes at a recovery voltage of 94 per cent of the rated voltage. The corresponding value of kVA broken was 692,000, or, based on the rated voltage, 735,000 kVA. The maximum time of arc duration was 3.19 half cycles, and the corresponding total arc length 3.3 inches.

The circuit breaker on all three parts of the test operated sharply but easily, there being but a very slight emission of smoke or oil from the vents. The total quantity of oil lost on the complete duty cycle was approximately 0.7 gallon.

To ensure that the circuit breaker had a satisfactory factor of safety it was subjected to an over-capacity test, during which it dealt with more than one million kVA in a perfectly satisfactory manner.

Following these over-capacity tests, an examination was made of the interior of the circuit breaker and a photograph taken which is reproduced in fig. 9. A moderate amount of burning had taken place at the arcing contacts but the circuit breaker was capable of carrying its rated normal load without first receiving attention. The main contact surfaces were unmarked and the arc control pots were in good condition, showing very little erosion of the plates.

A complete table of test figures, table 1, is included for comparison with the oscillograms in fig. 13.

In conclusion, acknowledgement is due to Edward Jones, Esq., M.I.E.E., Cardiff Corporation Electric Supply Department, for his kindness in giving permission for the publication of the information and illustrations contained in this article.

TABLE I.

Value per cent.	Duty Cycle.	Power Factor.	*R.M.S.* Line Volts kV.	Recovery Voltage per cent of rated voltage.	Peak kiloamps in first half cycle†	*R.M.S.* Kiloamps broken.†	kVA* broken.	Arc Duration in half cycles.†
10	B	0.1	37.2	100.0	2.6 2.6 3.35	1.28 1.27 1.31	73,900 (73,500)	12.5 6.64 12.1
	2 MB	0.1	35.5	97.5	2.9 2.05 3.2	1.30 1.31 1.33	73,200 (75,100)	6.6 6.65 7.38
30	B	0.1	38.0	100.0	9.3 6.3 10.3	3.89 3.92 3.95	224,500 (224,100)	3.77 4.95 4.32
	2 MB	0.1	36.1	100.5	7.8 7.68 6.0	3.92 4.0 4.03	229,000 (227,700)	4.33 3.54 3.67
60	B	0.1	38.5	87.6	24.9 30.3 21.8	9.13 9.6 9.34	468,000 (535,000)	2.61 3.3 2.52
	2 MB	0.1	37.3	98.0	17.7 26.7 24.9	10.4 11.4 11.0	612,000 (625,000)	3.3 2.52 2.52
100	B	0.1	38.5	97.0	23.6 32.5 36.3	12.6 13.5 14.5	750,000 (775,000)	1.64 2.09 1.91
	3 MB	0.1	37.3	92.5	22.0 33.0 29.8	12.0 12.6 12.6	655,000 (709,000)	3.64 3.27 2.55
	3 MB	0.1	37.3	94.0	36.0 22.5 35.0	13.2 12.4 13.0	692,000 (735,000)	2.55 2.55 3.19
133 approx.	B	0.1	38.5	106.5	29.5 34.0 25.0	17.1 19.8 15.1	1,061,000 (992,000)	3.0 1.77 2.96

† Where phase values are given read { R, W, B }

* kVA based on the *R.M.S.* current broken and recovery voltage.
kVA figures in brackets based on the *R.M.S.* current broken and rated voltage.

Automatic Control of Road Traffic.

WITH PARTICULAR REFERENCE TO THE "AUTOFLEX" SYSTEM.

Fig. 1.—Autoflex road traffic control installation at intersection of Southampton Row and Theobalds Road.

PART I.

By F. A. DOWNES,
A.M.I.E.E., M.I.R.S.E.

Traffic Engineer, The Siemens and General Electric Railway Signal Co., Ltd.

The author has divided this article into two parts. The first part, which appears below, gives a brief exposition of the elements of traffic flow, and the requirements of automatic mechanism for controlling traffic.

In the second part, which it is hoped to publish in the November issue of the G.E.C. Journal, details of the apparatus employed and an explanation of its operation will be given.

Fig. 2.—Road traffic signals and controller in New Oxford Street.

IT is only comparatively recently that the problems involved in the handling of road traffic, both vehicular and pedestrian, by automatic devices, have received serious consideration. The inception of the idea of automatic control cannot be traced to any one particular person, for mechanical aids have been used by traffic policemen in various countries for many years. It is only within the last few years that the characteristics of road traffic flow have been studied fully and in detail and it is probably more as a result of this study than of any other factor that automatic control devices have been introduced. Perhaps the greatest incentive to this study has been the necessity for providing some means of organizing the flow of traffic in congested thoroughfares, in order to avoid

further congestion and to enable the maximum volume of traffic to use the thoroughfare.

Traffic engineers have recently joined together in America to form an Engineering Institution to study traffic problems. In this country, the study of the problem is in the hands of traffic engineers in the Ministry of Transport and on the staff of the concerns manufacturing traffic control gear. Of these engineers probably no particular individual is able to devote his whole time to a purely theoretical and mathematical study of the problem. However, much useful work has been done in this country, particularly researches into the mathematics of probability and their application to traffic problems by W. F. Adams, of the Ministry of Transport, and N. H. Martin, of Siemens Bros. & Co. and The Siemens and General Electric Railway Signal Co., Ltd. Reference to their work will be made later, when describing traffic integrators.

As it is the purpose of this article to deal with automatic systems of control only a brief, though nevertheless essential, enquiry into the general behaviour and characteristics of traffic can be made.

USE OF AUTOMATIC DEVICES.

The first observation of traffic reveals the fact that it is only at busy intersecting roads in towns that automatic devices, such as signals, can be of real value in *assisting traffic flow*. In both town and country areas, however, automatic signals can be of value in making the *traverse of the intersections safer* for vehicles and, in special circumstances, can be provided for the benefit of pedestrians.

Fig. 3.—Tail of traffic leaving Church Street, Notting Hill Gate, on phase 2 (see plan, fig. 17).

VARYING DENSITY OF TRAFFIC.

Further study shows that varying density occurs at different times of the day; also that there are seasonal rises and falls. The rise in density during 24-hour periods usually coincides with the opening and closing of the business areas, with variable peaks during mid-day. In the case of some urban areas, a definite increase occurs at certain weekly periods due to market days and the like. Seasonal rises and falls are largely due to the increase in travel tendencies following fine weather or in anticipation of fine weather.

GROUPING OF TRAFFIC.

If special consideration is given to traffic flow in any particular road in an urban area, a tendency for traffic to move in squads or flocks is readily observable. This is largely due to the effect which the various cross roads have in breaking up the main flow of traffic; another factor in the formation of these blocks of traffic is the presence of large, slow-moving vehicles. The faster vehicles catch up with, and are held up behind, slow vehicles until an opportunity for passing is presented. This effect is accentuated in the case of trams and buses loading and unloading, particularly at recognized stopping places where these large vehicles congregate and form points of congestion at varying times.

It is not suggested that any form of automatic control at present under consideration can cure this, but when planning control schemes it is important to bear in mind the continual rise and fall in volume of traffic, and the cause of congestion.

CAUSES OF CONGESTION.

The chief causes of congestion are :—

(1) Obstruction by cross traffic at intersecting streets.
(2) Too great an amount of traffic for the width of carriage-way.
(3) Parking of vehicles.
(4) Large, slow-moving vehicles, *e.g.* horse-drawn vans, trams, etc., loading, unloading or moving at a slower speed than the general characteristics of the traffic would permit.
(5) A greater volume of vehicles travelling in one direction than in the other, causing obstruction by occupying a space greater than half the width of the road.
(6) Traffic turning to the right.

CAPACITY OF A SINGLE LANE OF TRAFFIC.

Theoretically, the only limit to the amount of traffic that can be dealt with by a single lane of

traffic, provided there is no obstruction or interruption of any sort, is that set by the limiting speed of the vehicles. In practice, however, it is also necessary to allow for the psychological effect on drivers when travelling at close intervals.

It is well known that vehicles travelling at high speeds have a tendency to space themselves more widely apart than those travelling at slow speeds, and it is this headway which, to a large extent, governs the total rate of the flow of the traffic.

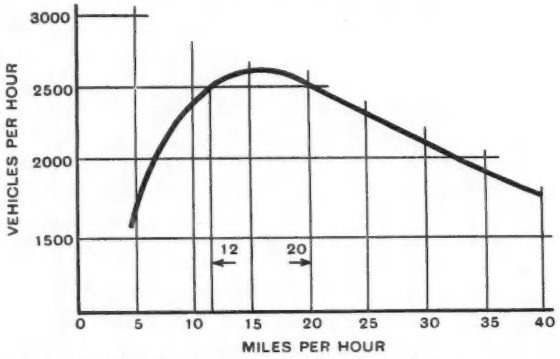


Fig. 4.—Relation between vehicles passing per hour with speed, showing optimum value at 15 m.p.h.

Calculations have shown that there is an optimum speed at which the greatest amount of traffic will be passed in a single lane. The generally accepted figure is of the order of 12-18 m.p.h. At the lower speed of 12 m.p.h. vehicles may be found to have only 15 feet headway, whereas at the higher speed of 18 m.p.h. the headway may be as much as 30 feet. However, this depends to a large extent on the

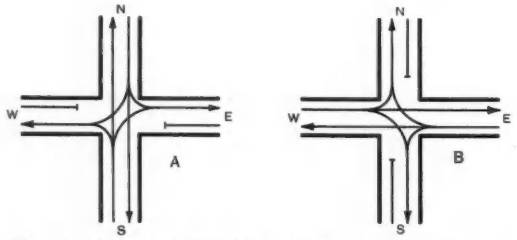


Fig. 5.—Plan intersection of cross roads used in the study of traffic flow.

class of traffic being handled, and one writer, for instance,[1] reproduces a curve which clearly shows a well defined optimum of 15 m.p.h. passing about 2,600 vehicles (fig. 4).

The optimum figure of 15 m.p.h. refers to dry roads of average surface, but in wet weather, this figure will be considerably decreased, except where a special non-skid road surface has been provided.

It is rarely that an uninterrupted stream of traffic is found in actual practice, and when considering the control of traffic by means of automatic devices, it is almost always necessary to provide a means of interrupting the flow of traffic at suitable intervals to allow the cross traffic to proceed.

As progress in the design of vehicles advances, and methods of braking and adhesion are improved, closer headway may be possible, and a traffic lane may be made to handle a considerably greater number of vehicles, and the optimum speed increased.

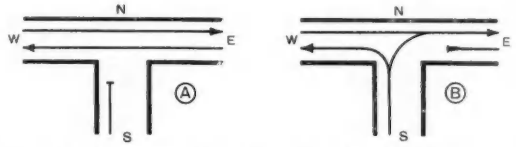


Fig. 6.—T-intersection of roads, showing two main movements of traffic.

TYPES OF INTERSECTIONS.

There are, roughly, five main types of intersections (figs. 5 to 12).

Actually, only the first type is an intersection in the true sense of the word, the remaining four being more in the nature of junctions, although there is a considerable amount of intersecting traffic.

The first type shown is a plain intersection, the second a T-intersection and the third a Y-inter-

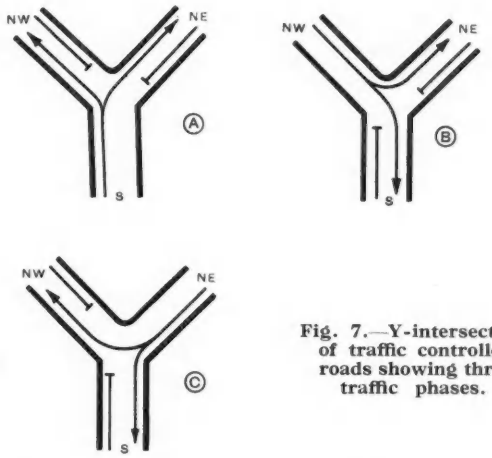


Fig. 7.—Y-intersection of traffic controlled roads showing three traffic phases.

section, which is merely a modification of the T-intersection. The fourth type, which is a staggered crossing, can be considered as two adjacent T-intersections in which the legs of the T are reversed. The fifth type is a multi-way intersection.

TRAFFIC FLOW AT CONTROLLED INTERSECTIONS.

The traffic flow at the first intersection (fig. 5), (assuming left hand traffic throughout), is divided into two main streams—north/south and east/west, with additional left hand turns which cause little or no complication to vehicular traffic, and right hand turns which are, at times, the cause of considerable congestion.

1— Harrison and Preist "Automatic Traffic Signalling."

In the case of the T-intersection (fig. 6, A and B) there are two main movements of traffic—east and west along the top of the T, and north into the top of the T. In the case of both movements

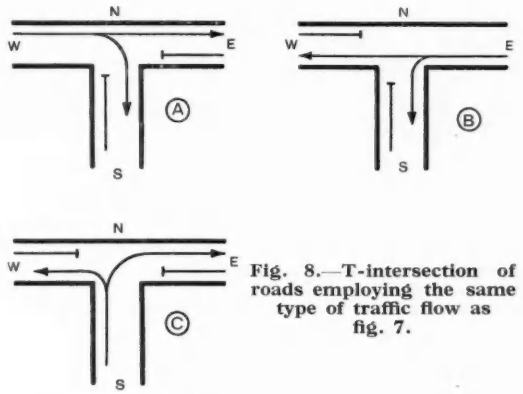


Fig. 8.—T-intersection of roads employing the same type of traffic flow as fig. 7.

the west to east traffic is not interrupted; usually the westbound traffic only is interrupted to allow traffic from south to go east.

In all cases under consideration when manual control is used, left hand turns are permitted at all times, but unless specially indicated, are not permitted with automatic control.

In the third case—the Y-intersection (fig. 7, A, B and C), there is only one really satisfactory method of traffic flow, and that is to treat each road separately and allow a separate running period for each in turn. This is shown diagrammatically, and the diagrams are self-explanatory. It will be seen that at no time are there any conflicting or intersecting moves, and it should be noted that the type of flow for the Y-intersection is equally applicable to the T-intersection and is, in many cases, to be preferred. This is shown in fig. 8 A, B and C. Here, again, left hand turns may be permitted under manual control, and would be indicated by special means for automatic control.

The fourth case, which is that of the staggered crossing, presents more or less difficulty, depending upon the distance apart of the two staggered limbs of the intersection. Generally speaking, the method adopted in fig. 9 A and B is satisfactory where the two limbs are fairly close together. It will be seen that the traffic flow is exactly the same as for a plain intersection of two roads, as shown in fig. 5.

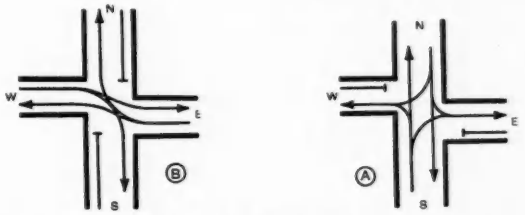


Fig. 9.—A staggered crossing with the two limbs fairly close together, using the same traffic flow as a plain crossing.

In cases where the limbs are staggered at greater distances, as in diagrams A, B and C of fig. 10, a somewhat different method of traffic flow has to be adopted, and there is a considerable difference between what is known as a left hand stagger and a right hand stagger. The difference will readily be appreciated by examination of the two sets of diagrams, A, B and C in figs. 10 and 11, which are reproduced beside each other for comparative purposes.

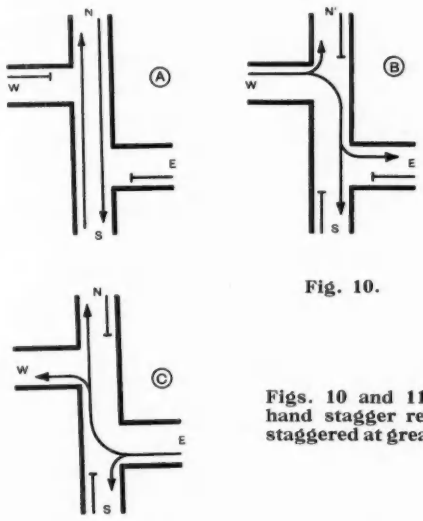


Fig. 10.

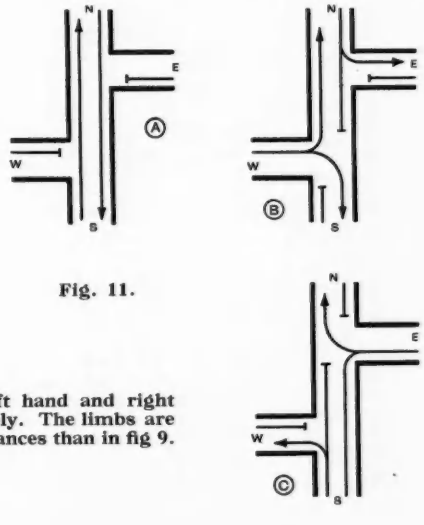


Fig. 11.

Figs. 10 and 11.—A left hand and right hand stagger respectively. The limbs are staggered at greater distances than in fig 9.

It is often the practice in the case of such staggered intersections, to allow the through road phase to occur twice in each complete cycle of changes; in other words, phase A would be followed by phase B and then phase A would be

allowed to run again, followed by phase C, the cycle then being complete.

An example of a multi-way intersection is shown in fig. 12, and here three traffic running phases are necessary, together with a fourth phase during which all traffic is stopped. It will be noticed that one of the complications of the intersection has been removed by making a street of minor importance into a one-way street.

In the case of phase A, northbound traffic only is allowed to flow, and is free to travel in any direction. Phase B then follows, during which traffic from the N.W. and N.E. is allowed to flow in

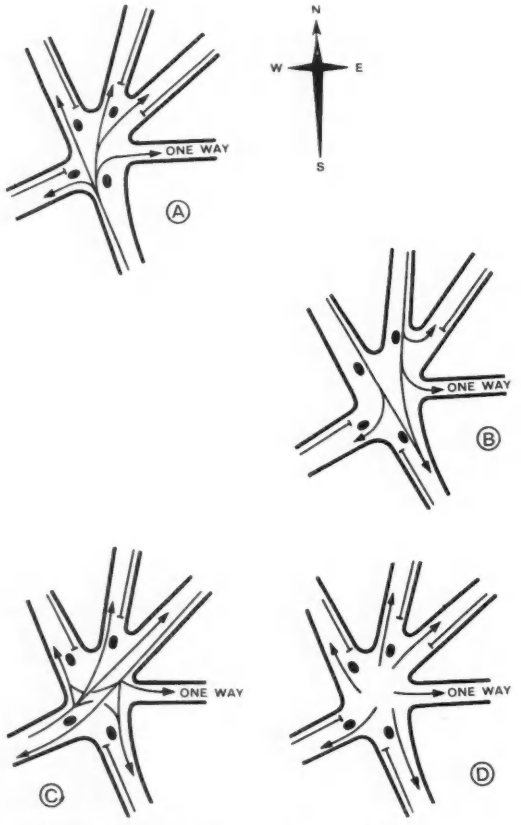


Fig. 12.—Multi-way intersection requiring three traffic running phases and a "stop" period to allow the traffic to clear.

all directions, traffic in all the other roads being stopped.

So far, only traffic flowing in similar directions has been allowed to pass at any time. In the case of phase C, however, both east and west traffic is allowed to flow, and right hand turns from east to north and from west to south are compelled to filter, as will be the case in any plain two-way intersection.

Following phase C is an all red, or "Stop," period which is necessary to allow traffic to clear from the intersection before the restarting of the cycle.

With many complicated intersections, it is advantageous to interpolate an all red period, which can be used for clearing the traffic from one phase before starting up the next phase, but recently this period has been used to permit pedestrians to cross.

A diagram is shown in fig. 13, illustrating an actual installation in which the southbound traffic in Clapham Road is stopped earlier than the northbound traffic in order to allow trams to turn right from Clapham Road into Stockwell Road. On the termination of this phase, both Stockwell Road and Binfield Road are opened, which is followed by Lambeth Road opening to allow traffic to flow in all directions.

NOMENCLATURE ADOPTED IN DISCUSSING TRAFFIC MOVEMENTS.

It is necessary that a recognized form of nomenclature be adopted to describe traffic movements, as without such means of description it is difficult to specify the performance required of any mechanism which is to provide automatic control of traffic. The usual method is to refer to traffic movements as phases, and fig. 9, for example, shows two traffic phases.

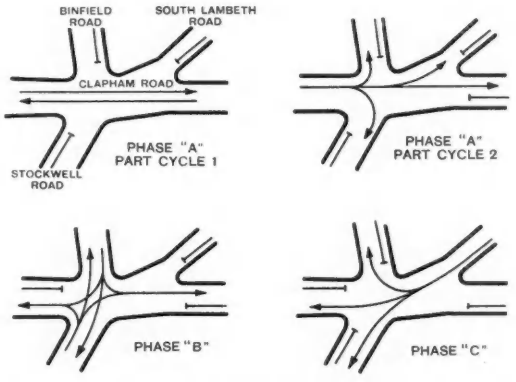


Fig. 13.—Traffic control arrangement where the Stockwell Binfield and South Lambeth Roads join Clapham Road.

Fig. 7 shows three traffic phases, whereas fig. 13 shows three traffic phases A, B and C, operating on what is usually termed a "three phase four-part cycle" method of control. This is because there are three major phases or traffic movements in the total cycle of events, yet, from a controller point of view, the cycle is split into four parts. The second part of phase A, that is to say part cycle 2, is in this case termed an "early cut-off" because the traffic is cut off earlier in one direction than in the other. The converse of this is a "late release" in which one part cycle or portion of a phase is released after the

other portion of the same phase. The time required to make a complete sequence of changes of phase is termed the "cycle time."

METHODS OF AUTOMATIC CONTROL AT AN INTERSECTION.

Signals. The first essential of any system of automatic control of traffic is some means of indicating "Stop" and "Go." Suggestions which have been put forward are many and varied, and range from the semaphore signals, as originally used at Brighton, to expanding and contracting neon rings, clockface indicators, rotating beacons and many other devices. The type of indication which has been standardized in this country, and, to a large extent, in other countries, is a colour light signal similar to that in use on certain railways. The colour sequence which is now used throughout this country has been adopted as the result of a circular issued in September, 1929, to all Local Authorities by the Ministry of Transport. This memorandum contained a recommendation that a three colour system should be adopted, using the colours red, amber and green with the red and amber overlapping on a transference to a green indication, but with the amber showing alone on transference to the red indication. It was also recommended that as a minimum, all drivers should be given two definite indications—one on the left hand corner of the intersection and the other on the right hand far side of the intersection, so that should the view of the signal on the near or left hand side be obstructed by a large vehicle or other obstruction, an alternative indication could be seen. This was the origin of the present two-way signal heads now in use throughout the country. The alternative, or as it is better known, secondary signal for one direction of traffic can be mounted on the back of the primary signal for the traffic approaching in the opposite direction, the two being mounted together on the same post. It was also recommended that, where necessary, a third series of aspects should be fitted on the same post and at right angles for the guidance of pedestrians, and, in some cases, to serve as a third or tertiary signal for the road traffic. A perspective drawing of a typical road intersection controlled by four 2-way signal heads is shown in fig. 14.

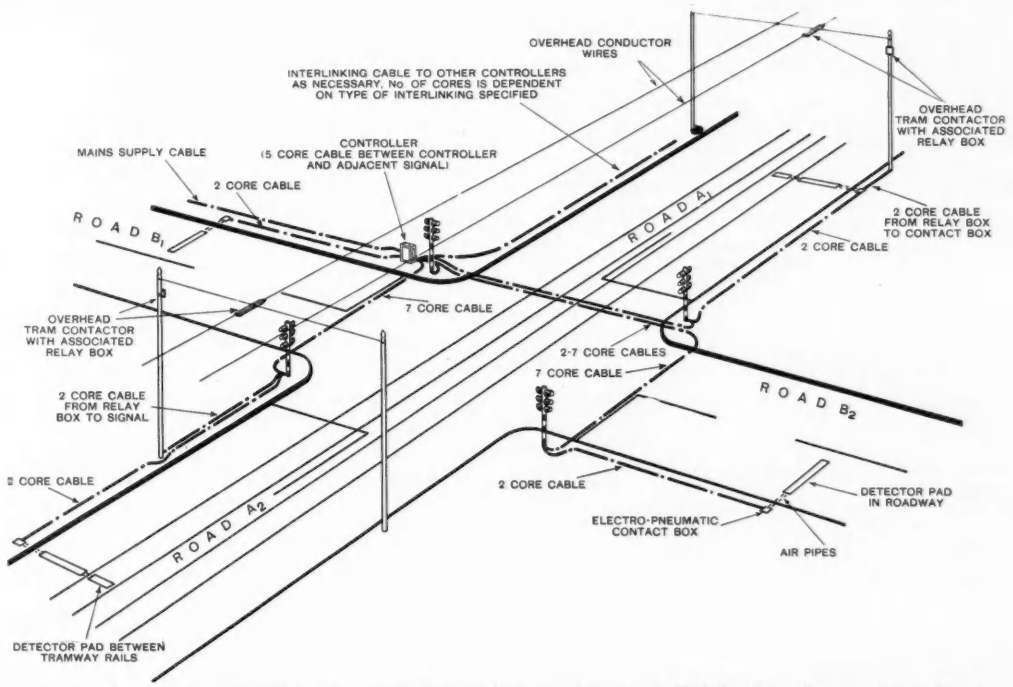

OVERHEAD CONDUCTOR WIRES
INTERLINKING CABLE TO OTHER CONTROLLERS AS NECESSARY. No. OF CORES IS DEPENDENT ON TYPE OF INTERLINKING SPECIFIED
OVERHEAD TRAM CONTACTOR WITH ASSOCIATED RELAY BOX
MAINS SUPPLY CABLE
CONTROLLER (5 CORE CABLE BETWEEN CONTROLLER AND ADJACENT SIGNAL)
2 CORE CABLE
ROAD B1
ROAD A1
2 CORE CABLE FROM RELAY BOX TO CONTACT BOX
2 CORE CABLE
7 CORE CABLE
OVERHEAD TRAM CONTACTOR WITH ASSOCIATED RELAY BOX
2-7 CORE CABLES
7 CORE CABLE
2 CORE CABLE FROM RELAY BOX TO SIGNAL
ROAD B2
2 CORE CABLE
2 CORE CABLE
DETECTOR PAD IN ROADWAY
ELECTRO-PNEUMATIC CONTACT BOX
ROAD A2
AIR PIPES
DETECTOR PAD BETWEEN TRAMWAY RAILS

Fig. 14.—Perspective drawing of a typical road intersection controlled by four 2-way signal heads.

Before leaving the question of indications it is interesting to note that many suggestions have been made as regards the provision of some means of indicating to the oncoming traffic how much time is left for either the green or red light—in other words, how soon changeover of indication may be expected. In one design a number of concentric neon rings are employed. For example, the full green indication would consist of three such rings, the number of rings illuminated indicating how much time is still available before a change of indication. Another device embodies a dial divided into two portions, one of which is painted red and the other green, the indication being given by a large hand travelling in a clockwise direction. The amount of

Fig. 15.—Signals at Woburn Place—Tavistock Place.

time left before a transference of indication is indicated by the position of the hand relative to the coloured background. Other devices include one having a multiplicity of lenses and the like. It is not practicable to use these time indicator signals with vehicle control, as the length of the "Go" and "Stop" periods fluctuates continually with the amount of traffic flowing.

CONTROLLERS.

Fixed time control. When road signals were first introduced a controller mechanism was provided which changed the green indication from one road to another at fixed intervals, an amber indication being interposed, as laid down in the Ministry's memorandum referred to previously. A large number of different mechanisms were available, all productions of different manufacturers. The majority used a motor drive, operating the lamp switches through a train of gears, the motors ranging from universal commutator motors to induction disc motors. An unusual form of controller was that manufactured by the Siemens and General Electric Railway Signal Co., Ltd., in which the timing periods were regulated by a piston moving up and down in a mercury dash pot and functioning by means of a ratchet gear, a switching drum controlling the lamp relays.

An interesting type of controller was also produced by another manufacturer, which used a neon tube timer in conjunction with a uniselector and mercury relays.

Incorporated in all these controllers, working on a time basis, was a means of adjusting the ratio of green showing to one road to green to be shown to the other road.

VEHICLE-ACTUATED CONTROL.

It was not long before complaints were made that with the fixed time, or as it is officially termed, "time controlled" method, vehicles had to wait at a red light at a cross road which was carrying no traffic at all, and it was felt that whilst time controlled signals were of great benefit, there was considerable room for improvement. The first advance in this direction came from the U.S.A., and consisted of a semi vehicle-actuated system produced by the Automatic Signal Corporation of America. With this system, pads (or as they are better termed, "vehicle detectors") were placed in the minor roads and the controller mechanism was so arranged that a green indication was normally given to the main road. When a vehicle approached on the side road the green was then transferred to the side road, and, in due course, after the passage of the vehicle in the side road, right-of-way was transferred back to the main road. It was not long before the same company produced a complete vehicle-actuated scheme with vehicle detectors in all four roads, and this system, which was named the "Electromatic" system, was introduced into this country in March, 1932, by their British representatives. The first installation was at the intersection of Cornhill, by Bishopsgate, in the City of London. This installation proved to be a great success, and from this time onward the popularity of the time controlled systems began to wane and the number of installations of vehicle-actuated systems rapidly increased. Later, a full vehicle-actuated system was produced by the Siemens and General Electric Railway Signal Co., Ltd., bearing the trade mark "Autoflex." This system offered similar facilities to the "Electromatic" system, but achieved its results in an entirely different and original manner.

REQUIREMENTS OF AN IDEAL VEHICLE CONTROLLED SYSTEM.

In order to obtain a proper understanding of the reason for certain electrical circuits in the controller mechanism, it is necessary first to consider the fundamental requirements which the switching mechanism should be capable of performing automatically. This mechanism must control the signal lights in such a manner as to give right-of-way and protect vehicles, subject to the following minimum conditions :—

1. The indications given by the signals shall be in accordance with the requirements of the Ministry of Transport.
2. The mechanism operating the indicating lights shall be so arranged that it is, so far as is practicable, impossible for right-of-way indications to be given to conflicting roads or streams of traffic.
3. Before a transference of right-of-way from one road to another shall be made, an amber warning shall be given.
4. A right-of-way indication shall be given to a vehicle to cross an intersection immediately the vehicle arrives within a predetermined distance of its appropriate signal. This right-of-way shall not be given immediately if a vehicle or vehicles in the intersecting road or roads has already registered a prior demand for right-of-way.
5. Vehicles arriving at roads to which a stop indication is showing, shall register their demand for right-of-way, which shall be stored until the end of the pre-set limiting period, as in 7 below.
6. The right-of-way, as indicated by the signals, must be sufficiently long to allow a vehicle or vehicles to which the indication is given to be clear of the intersection before a change of right-of-way to another road is given.
7. In the event of continuous traffic on any road it shall be possible to limit the right-of-way on that road if a demand is received from a conflicting stream of traffic.

Consideration of the foregoing minimum requirements makes it quite clear that some means must be provided of indicating to the control mechanism the arrival or passage of vehicles, and for this purpose road vehicle detectors are provided. It is also clear that the apparatus must be capable of storing demands received from the road vehicle detectors and utilising these demands at the appropriate time. The mechanism must also be capable of converting the information received from vehicle detectors into the appropriate signal indications under the conditions already enumerated above.

CO-ORDINATION OF TRAFFIC AT ADJACENT INTERSECTIONS.

In the case of roads intersecting important thoroughfares, it has been found that where these intersecting roads are separated only by distances of approximately 400 ft. or less measured along the main road, it is necessary to co-ordinate the traffic flow at each intersection. The necessity for this is made clear upon consideration of an assumed case where two adjoining intersections in a main thoroughfare are provided with automatic control. If the signals at intersection No. 1 are passing traffic through to intersection No. 2 at a time when No. 2 is dealing with the cross traffic, it is evident that in a very short period the traffic freed from No. 1 will fill in the space of the main road between 1 and 2 and eventually this queue of traffic will reach back across the intersecting road of No. 1. Accordingly, when the time comes for the controlling mechanism at No. 1 to change over the right-of-way to the crossroad, the crossroad traffic is then unable to flow because of the queue of main road traffic stretching right across the intersection. It is evident from consideration of such cases as the above that co-ordinated working between signals at adjacent intersections is absolutely necessary under such circumstances. A further requirement is therefore added to the list of functions which the automatic controller shall perform, namely, a facility for interlinking electrically and thereby co-ordinating the indications given to the traffic.

GRAPHICAL METHOD OF PLANNING TRAFFIC FLOW FOR CO-ORDINATED SYSTEMS.

An idea of the way in which co-ordinated systems are planned is given in fig. 17, which is a small scale reproduction of four intersections in Notting Hill High Street, Kensington, while underneath, in their relative positions to the intersections in question, are shown the actual traffic phase diagrams. These phase diagrams are produced as a result of a detailed examination of the traffic at each of the intersections at various times of the day, and before any attempt is made to allot timings to any of the phases, a comprehensive traffic census is made and studied.

Fig. 16.—Installation of Autoflex signals showing, on the right, the signals bracketed to an existing lamp standard.

As soon as individual phase diagrams for each intersection have been made, a further diagram indicating the amount of co-ordination between the individual intersections has to be prepared. Such a diagram is shown in fig. 18. This diagram is for the Notting Hill section, reproduced in fig. 17. The usual method adopted in the preparation of such diagrams is to reproduce on a small scale plan all the intersections showing the various signals, and this small diagram represents the ordinate of the embryo traffic diagram. The abscissa is in the form of a time base upon which the diagram is built. With knowledge of the amount of traffic using the through road, it is generally possible, as a start, to choose a speed of travel upon which a trial diagram may be made, and in this connection it is well to bear in mind that the curve reproduced in fig. 4 showing an optimum speed of 15 m.p.h. holds good when choosing a speed for the preliminary graph—in other words the lower speed limits chosen would be of the order of 10 m.p.h. and the higher speeds of 20 m.p.h. Having chosen a suitable speed for a trial, a line is drawn at an angle which represents the distance of travel in the time required. The colours of the signals can then be drawn in their correct positions to a time scale having durations which were considered desirable when the first phase diagrams were drawn. It is then possible by judicious re-arrangement of the indication timings and the slope or speed of the through traffic to arrive at a satisfactory combination of traffic "band width" and speed of flow. Fig. 18 shows an actual diagram to which the traffic is operating in Notting Hill High Street. The base of this diagram is marked off in pulses instead of seconds: the reason for this will be discussed later.

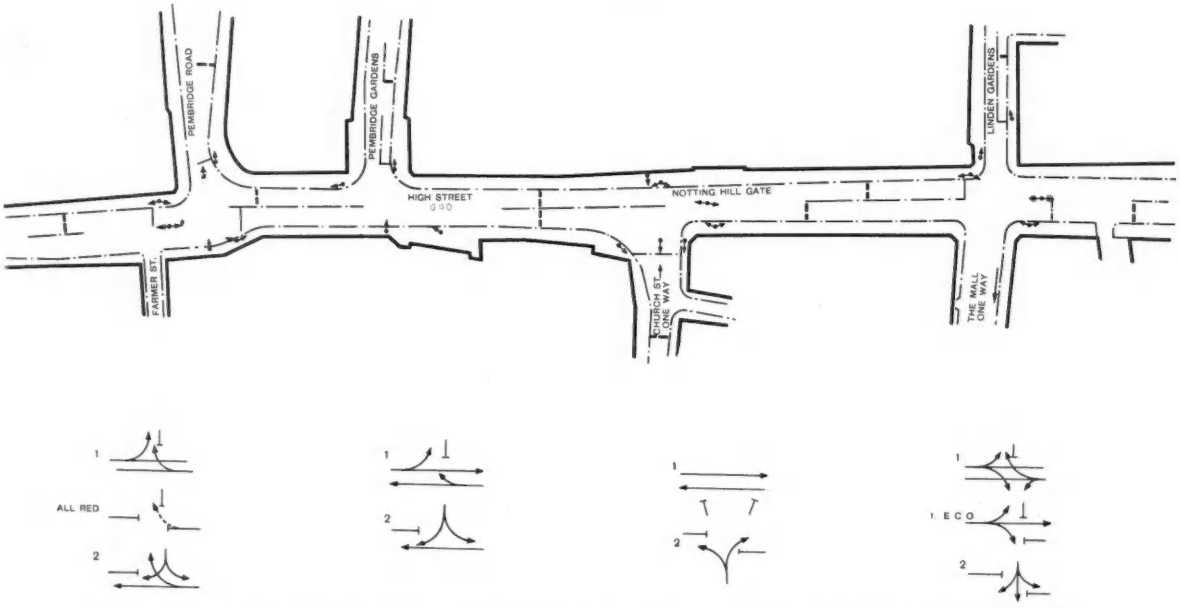


Fig. 17.—The four intersections at Notting Hill Gate. Below the plan are given the actual traffic phase diagrams as used when planning co-ordinated systems.

METHODS OF CO-ORDINATION.

Autoflex controllers can be interlinked in several ways. The method most preferred, however, is one in which a master controller sends out two pulses per cycle to each local controller, one pulse of which indicates the start of the main road preference period, as indicated on the time distance diagram, while the other pulse indicates the start of the side road preference period. These pulses do not definitely force a change to the roads in question unless there are demands from the traffic in the appropriate roads.

A prevent period is provided to ensure that the side road traffic does not interrupt that of the main road when the latter is flowing in its correct preference period. It is necessary that the beginning of the preference periods at each intersection is arranged in a correct sequence to give progression of traffic as indicated on the traffic diagram. This is achieved by dividing the cycle time into 25 steps, and 25 switches per pulse per local controller are provided at the master controller, giving a choice of 25 different available settings of preference period for each local controller.

Further developments of the Autoflex progressive system provide for 50 divisions of cycle time with alternative facilities enabling all progressive timing adjustments to be centralized in the master controller or decentralized and situated in the local

controllers. In the latter case a common pair of tie lines only is necessary for all local controllers.

In the methods of co-ordination described, the use of detectors in both main and side roads has been considered, but an Autoflex co-ordinated system is available in which vehicle detectors are used in the side roads only, the right-of-way indication being arranged to revert to the through road for a fixed period, which can only be extended in the absence of traffic in the side road. Side roads receive right-of-way in proportion to the amount of traffic arriving. In operation, this method does not vary greatly from the system in which detectors are provided in all roads, provided the majority of the traffic uses the main thoroughfare and the side roads are comparatively lightly loaded. There is

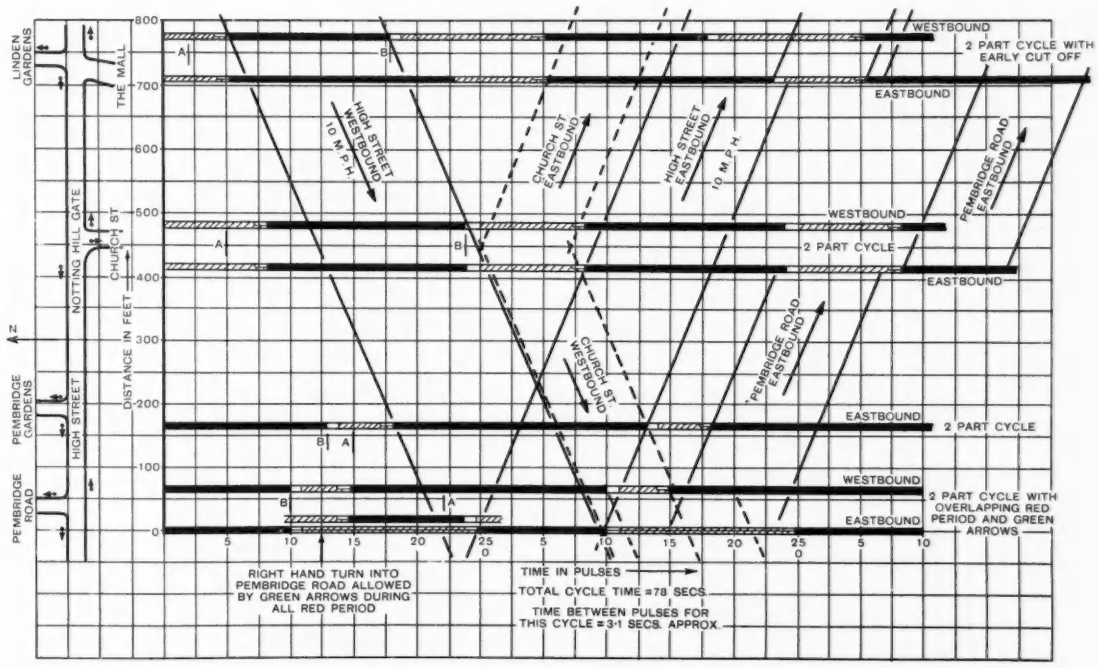


Fig. 18.—Diagram indicating the amount of co-ordination between the individual sections at Notting Hill Gate.

also some saving in the initial cost of such an installation, due to the reduction in the number of vehicle detectors required.

CONTROL OF CYCLE TIME (TRAFFIC INTEGRATORS).

The cycle time on which many traffic diagrams are based is for the maximum observed traffic flow. In most cases the cycle time can be decreased and traffic flow speeded up when there is a decrease in traffic density. To accomplish this, a traffic integrator is provided to vary the cycle time as required. The cycle time is not varied in direct proportion to the amount of traffic, but follows a non-linear law, which may vary for different installations. Generally speaking, it follows a common outline. Such a curve for traffic integrator settings is reproduced in fig. 14. For convenience this curve is divided into two halves, a rising curve and a falling curve. In these two curves, B shows the individual traffic counts over five minute intervals, so that the vehicle readings to the left of the two curves represent $\frac{\text{vehicles per hour.}}{12}$

Curve A represents the gradual rise and fall of the traffic, and it will be observed that the five minute peaks are smoothed out. Actually, however, the volume of traffic is varying rapidly from minute to minute, but such variations need not be covered by the traffic integrator as they are handled by the vehicle-actuated control at the various intersections. The function of the traffic integrator is to determine by what amount the volume of traffic has increased or decreased, and, having found the new level at each time of measurement, adjust the total cycle accordingly. The most satisfactory method of performing this duty electrically, is to count the number of vehicles passing the key intersection in a given period of time, which should be sufficiently long to cover the small instantaneous changes which take place. Five minutes is considered ample time to cover these momentary fluctuations, and yet short

enough to give 12 different cycle time adjustments in the hour. For this reason the curve in fig. 19 is plotted to a base of five minute intervals. As a result of summations completed at the end of five minute intervals, the integrator adjusts the total cycle to a new figure, which is slightly in arrear of the actual rise or fall of the traffic flow for which the cycle time has to be compensated. This lag applies to both rising and falling traffic. Experience has shown that a range of cycle time from 30 to 120 seconds in equal steps of $2\frac{1}{2}$ seconds will cover all normal conditions. The manner in which the integrator carries out the counting and adjustment will be dealt with in the technical description of the apparatus. It is necessary that the integrator, before making a new setting, shall have recorded the previous setting in order to determine whether the new reading represents a rise or a fall upon the previous reading. Curve C, which is the dotted curve, gives the setting of the integrator as it approaches the observed values. The actual performance required of the integrator is shown in curve D, which provides a factor of safety found necessary by experience.

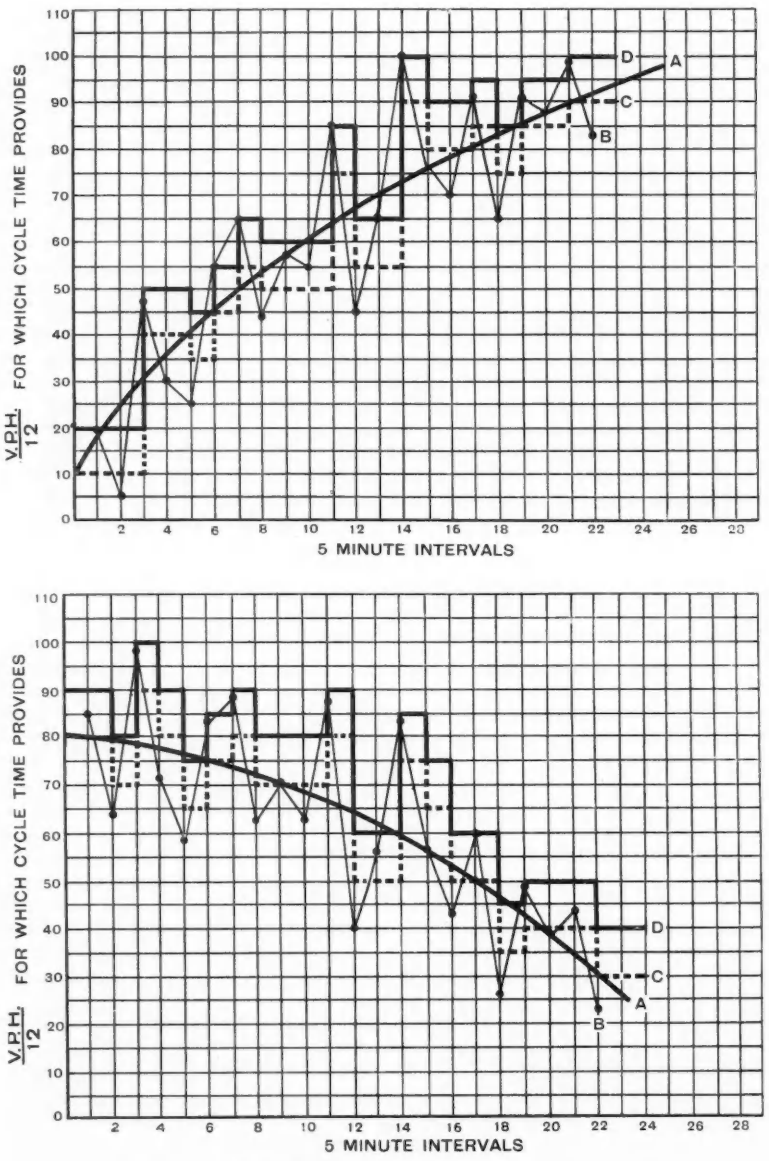


Fig. 19.—Curves of traffic integrator settings, above rising and below falling.

It may appear from the beginning of this section that undue attention has been paid to the elements of traffic flow, but it is very necessary that a study of these elements should be made, otherwise the operation of the controllers, which are to be described in Part II of this article will not readily be understood. The author therefore trusts he may be forgiven for pointing out certain obvious and, perhaps, elementary characteristics in the flow of traffic.

[*To be continued*].

The Testing of Large Alternating Current Circuit Breakers.

PART IV.—TRANSFORMERS AND REACTORS.

By JOSEPH GOODMAN, A.M.I.E.E., A.M.I.Mech.E.
Chief Transformer Engineer, Witton Engineering Works.

DESIGN OF TRANSFORMERS.

AS stated in previous sections of this article the alternator in the High Power Test Laboratory at Witton has been designed for a normal instantaneous output during the first half cycle of 2,000,000 kVA and a boosted output of 2,800,000 kVA at voltages up to 22 kV[1]. These values are increased by approximately 45 per cent if the asymmetrical current is taken into consideration. For voltages higher than 22 kV, power must be transmitted through step-up transformers.

Three transformers have been installed for this purpose (fig. 40) designed to transmit the power developed by the alternator and to step up the voltage to the various voltages likely to be required from the testing plant. Fig. 41 is a diagram showing the connections and winding arrangements necessary to obtain these voltages.

1.—G.E.C. Journal, Vol. VII., No. 1, p. 80, and Vol. VII., No. 2, p. 116.

The maximum power output of the transformers is limited by their reactance and it was thus important to keep the reactance as low as possible. The value actually obtained is 2.53 per cent. This consideration, which is of the first importance, determined the most suitable type of transformer and it was decided to use single phase transformers of a modified shell type, which are not only mechanically strong and employ circular coils, but also permit of the close interleaving of the H.V. and L.V. coil-groups necessary to obtain the extremely low reactance figure required. Careful consideration also had to be given to the power factor of the combined transformer and alternator. It was found that a satisfactory figure was obtained by allowing an IR drop for the transformer of 0.4 per cent at 50,000 kVA.

The transformers are capable of withstanding (thermally and mechanically) a maximum *R.M.S.*

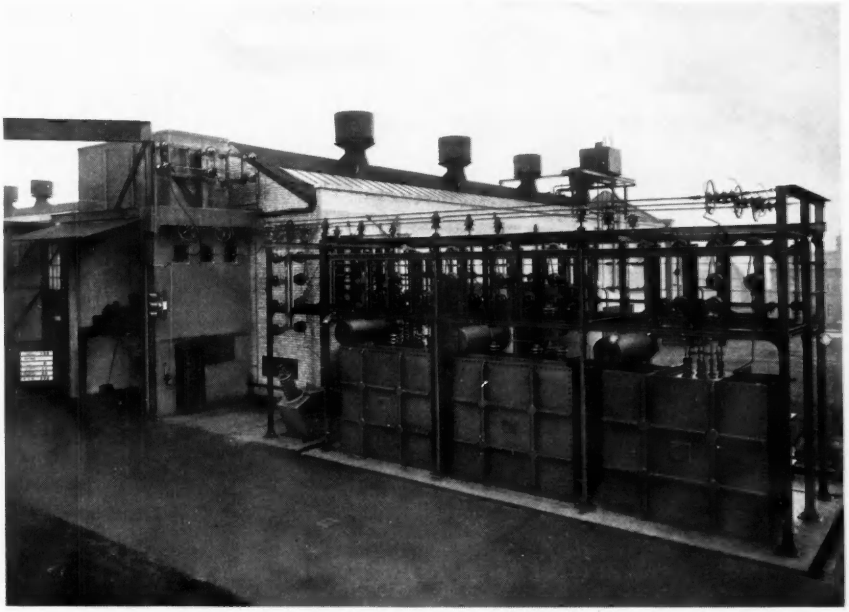
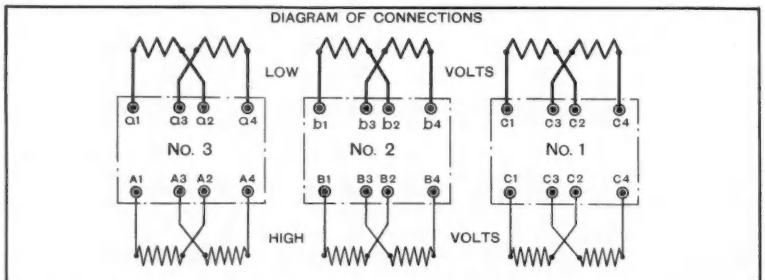


Fig. 40.—View of the High Power Test Laboratory at Witton Engineering Works, seen from the test bay end. In the foreground are the step-up transformers.



	TESTS	THREE PHASE		SINGLE PHASE				
PRIMARY	SUPPLY FROM GENERATOR	11,000	22,000	11,000		22,000		
	CONNECT LINES TO	a4c1-b4a1--c4b1	a4c1-b4a1--c4b1	a4 b4 c4 – a1 b1 c1		a4 b4 c4 – a1 b1 c1		
	INTERCONNECT BETWEEN TRANS. ON L.V.	a4 - c1 b4 - a1 c4 - b1	a4 - c1 b4 - a1 c4 - b1	a4 - b4 - c4 a1 - b1 - c1		a4 - b4 - c4 a1 - b1 - c1		
	CONNECT ON TRANSFORMERS L.V.	a1-a3:a2-a4 b1-b3:b2-b4 c1-c3:c2-c4	a2 - a3 b2 - b3 c2 - c3	a1-a3:a2-a4 b1-b3:b2-b4 c1-c3:c2-c4		a2 - a3 b2 - b3 c2 - c3		
	GROUP CONNECTION ON L.V.							
SECONDARY	VOLTAGE ON SECONDARY	33,000	66,000	19,050	38,100	76,200	57,150	114,300
	BETWEEN LINES	A4 - B4 - C4	A4 - B4 - C4	A4B4C4 - A1B1C1	A4B4C4 - A1B1C1	A4 - B1 C1	A4 - C1	A4 - C4
	INTERCONNECT BETWEEN TRANS. ON H.V.	A1 - B1 - C1	A1 - B1 - C1	A4 - B4 - C4 A1 - B1 - C1	A4 - B4 - C4 A1 - B1 - C1	A1 - B4 - C4 B1 - C1	A1 - B4 B1 - C4	A1 - B4 B1 - C1
	CONNECT ON TRANSFORMERS H.V.	A1-A3:A2-A4 B1-B3:B2-B4 C1-C3:C2-C4	A2 - A3 B2 - B3 C2 - C3	A1-A3:A2-A4 B1-B3:B2-B4 C1-C3:C2-C4	A2 - A3 B2 - B3 C2 - C3	A2 - A3 B2 - B3 C2 - C3	A1-A3:A2-A4 B1-B3:B2-B4 C1-C3:C2-C4	A2 - A3 B2 - B3 C2 - C3
	GROUP CONNECTION ON H.V.							6 IN SERIES

Fig. 41.—Diagram showing the primary and secondary connections obtainable with the testing transformers.

load of 850,000 kVA. The transformer bank, which has a total nominal rating of 50,000 kVA, therefore comprises three 16,666 kVA single phase transformers.

CONSTRUCTIONAL DETAILS.

The construction of the core and the windings is shown in figs. 42 and 43. The iron core before the windings have been fitted is seen in fig. 42. The core is of the standard stepped pattern suitable for the mounting of circular coils. The massive design of the core plates and end clamp construction plates is clearly shown. The completely assembled windings in their frame or cage, before placing on the core are illustrated in fig. 43.

The windings consist of a number of H.V. and L.V. disc coils. Each coil is wound with heavy section d.c.c. copper strip insulated with double half-lap tape, which at a later stage is varnish impregnated under vacuum treatment. Between each pair of turns is also wound a pressboard spacer, while the coils in each group, whether H.V. or L.V., are insulated from each other by pressboard washers. Pressboard is also used as the major insulation in the form of washers inserted between the H.V. and L.V. groups.

Owing to the large internal diameter of the coils, special arrangements were made to facilitate winding so that a smooth-surfaced, tightly wound coil was obtained.

The disc coils, as previously stated, are arranged in the H.V. and L.V. groups, and are assembled on a heavy bakelite-micarta cylinder, care being taken to ensure that the H.V. and L.V. coils are exactly balanced electro-magnetically by control of the radial depths and the internal diameters of the various coils.

Care was also necessary in insulating the inter-coil and inter-group insulation in order to ensure that sufficient clearance and/or leakage distance existed between the coils and coil groups, without lessening the mechanical strength at these points.

The complete coil stack, when assembled, is clamped between fabricated headers, one at the top and one at the bottom, the headers and intervening coil stack being held together by four 3in. clamping rods. The headers are made of a chrome alloy steel, having an ultimate tensile strength of 37/43 tons per sq. in.,

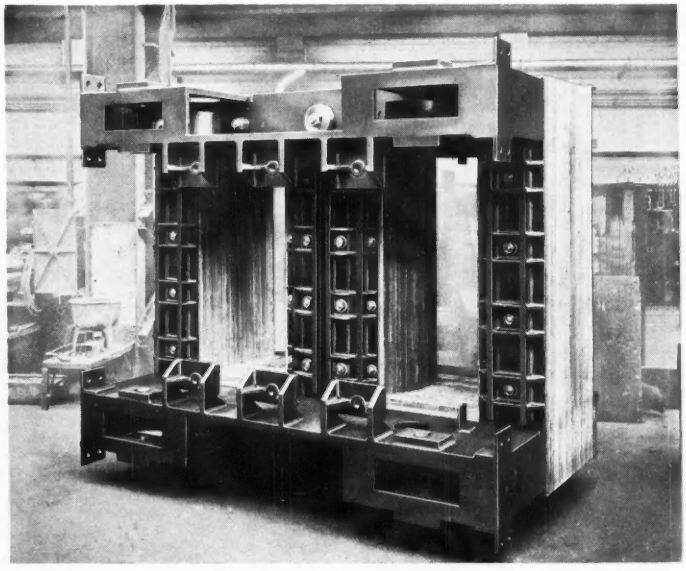


Fig. 42.—Core construction of one of the High Power Test transformers.

whilst the 3in. clamping rods are of a special steel having an ultimate tensile strength of 65 tons per sq. in.

When assembled, the coil stack and end headers form a complete separate winding unit, in no way dependent on the remaining structure for the actual rigidity and clamping of the winding. The unit is fixed to the core structure by an extension of the four main clamping rods. Details of the coil assembly and coil clamping structure are shown in fig. 44.

Reverting to the individual disc coils, each coil after being removed from the winding lathe was clamped between special surface plates to ensure that the turns of each coil were bedded down correctly and in line ; also, before final assembly this method of clamping was carried out on the various groups both before and after vacuum treatment. Although this clamping process involved considerable labour, it was considered absolutely essential in order to make certain that when the coils were completely assembled no final levelling-up would be necessary between turn and turn in individual coils, and that a true surface would be presented to the pressboard washers inserted between the H.V. and L.V. groups.

It may be pointed out here that the space factor in these transformers is of necessity much smaller than in an ordinary power transformer, due principally to the special pressboard washers used. The presence of this pressboard in the form of large annuli of great radial depth, raised another problem, namely, a determination of the method of drying out such large masses of hygroscopic material. Tests of the hygroscopic and oil absorption properties of similar washers were therefore made in the Development Laboratory at Witton, and the results

Fig. 43.—The windings for one of the transformers completely assembled in their cage.

proved that the proposed works processes were correct. Special experiments also were made to determine the force necessary to be applied to the clamps to obtain a matured coil that would be entirely free from subsequent shrinkage.

One of the single phase transformers, completely assembled and ready for installation in the tank, is shown in fig. 45. It will be seen that the transformer is mounted on its side and the core is ade-

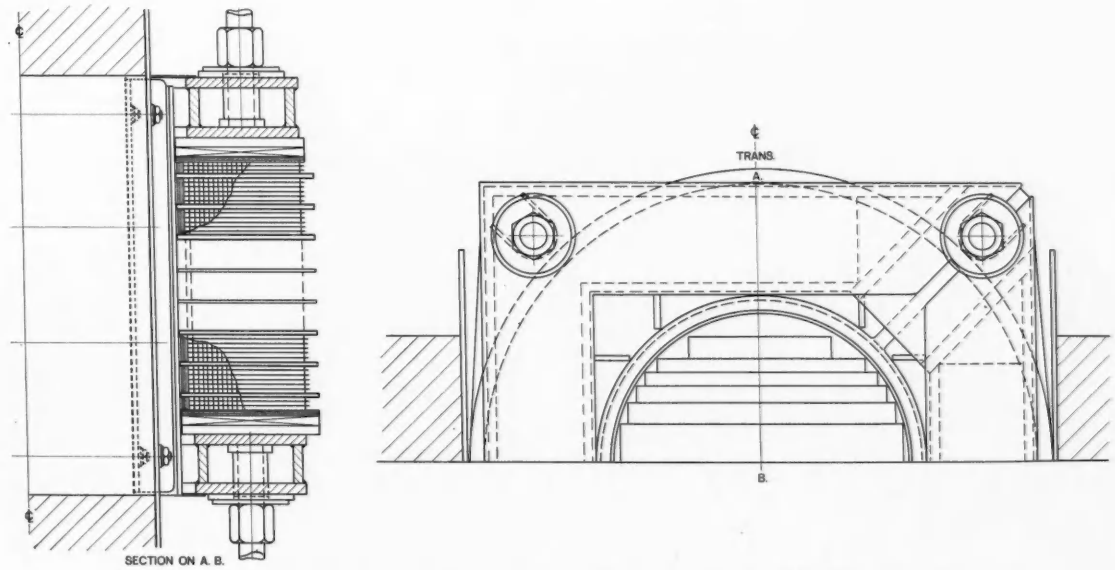


Fig. 44.—Arrangement of the coil assembly and coil clamping structure.

quately supported by the external structure, while the winding cage is supported independently from the laminated core. The core and windings are bolted to the base of the tank, which in turn is so fixed to the supporting plinth that any mechanical shock which may be produced in the core and windings during a test is transmitted direct to the plinth. All winding terminals are mounted at the top of the transformer, while rollers are fitted on the base to enable the transformer to be easily installed in its tank.

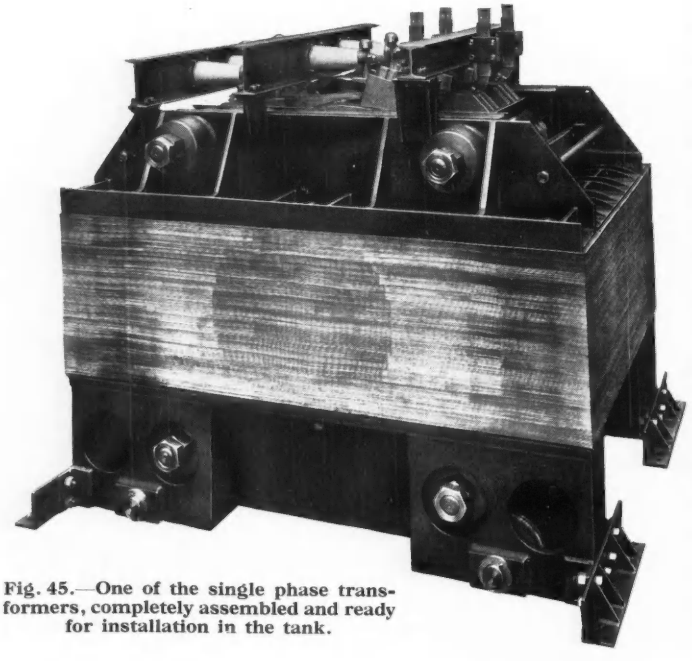


Fig. 45.—One of the single phase transformers, completely assembled and ready for installation in the tank.

To avoid undue strain on the copper connections external to the actual windings, arrangements are made to provide flexible couplings in all main leads.

A single phase transformer in position in its tank is shown in fig. 46 ; the channels which act as roller guides may be seen. This illustration also shows the general proportions of the fixing and terminal supports.

TANK.

A rectangular tank of massive construction is employed and is provided with guide-rails at the bottom to take the rollers on the transformer ; one end wall of the tank is removable and forms the means of access to the interior ; this enables the transformer to be withdrawn from the tank on its own rollers.

Sufficient clearance is allowed between the core and windings and the tank walls and roof to permit of easy inspection of the transformer and terminals when the detachable end of the tank is removed.

In view of the short time rating of the transformers no cooling tubes or radiators are required, but other usual fittings such as a conservator and the like, are provided.

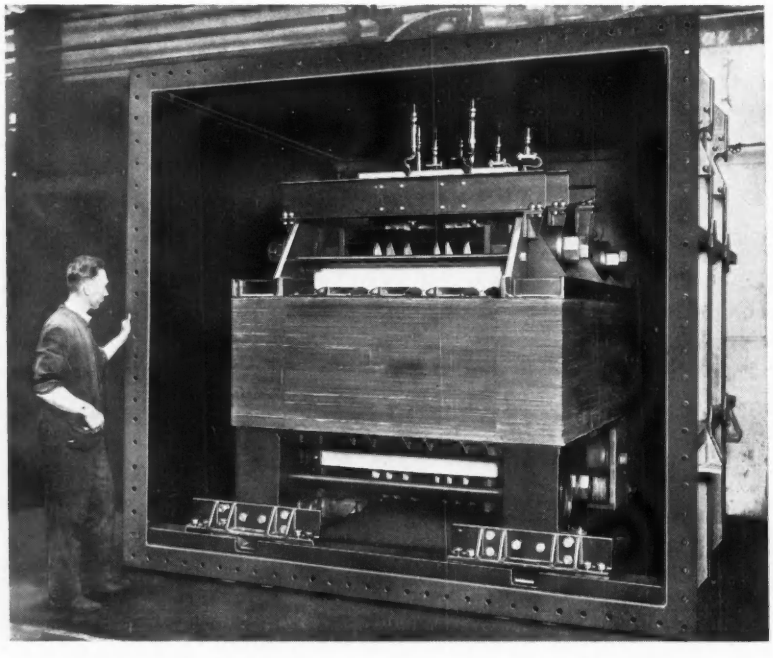


Fig. 46.—A single phase transformer in position in its tank.

When the transformers were assembled in their tanks, they were subjected to a very carefully controlled drying out process which extended over several weeks. This process was entirely separate from and independent of the previous vacuum drying and impregnation processes carried out on the windings.

The oil used is of the standard class A.30 type, complying with British Standard Specification No. 148. It was carefully filtered before use, and gave dielectric test results which were much higher than the minimum requirements of this specification.

The weight of each single phase unit is approximately 50 tons.

REACTORS.

The provision of suitable reactors is necessary in such a test plant in order to regulate the magnitude of the short circuit that is to be applied. Four single phase reactors per phase are installed, *i.e.*, a total of twelve reactors, each having a reactance of 1 ohm. Thus, a total maximum reactance per phase of 4 ohms (four in series) is available.

The reactors are arranged in two tiers and are of the concrete air cooled type. They differ from the standard air cooled type in that the copper windings are solidly embedded in concrete. Under the most onerous conditions of operation the temperature rise is well within safe limits, whilst this particular construction obviously increases the mechanical strength of the reactors.

The battery of reactors assembled in position

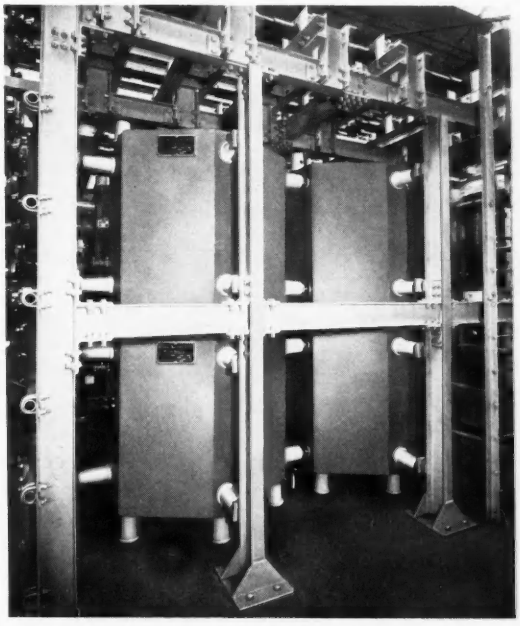


Fig. 47.—Reactors forming a single phase bank installed in the generating station.

in the power house is shown in fig. 47, and fig. 48 illustrates a half section of the reactor.

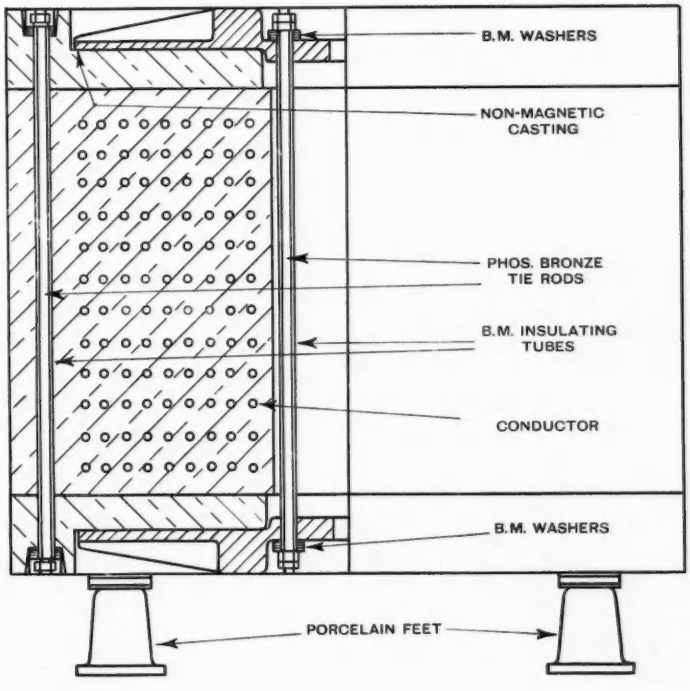


Fig. 48.—Sectional view of one reactor showing construction.

PART V.—INSTRUMENT EQUIPMENT.

By J. S. CLIFF, A.M.I.E.E.
Testing Engineer, High Power Test Laboratory, Witton.

IN any form of testing, the measuring and recording equipment is of great importance; but special interest attaches to the meters and instruments employed for short circuit investigations, not only because of the unusual magnitude of the values to be measured, but also on account of the wide variety of the quantities dealt with and their very transient nature. A single test may involve the recording of currents up to several hundred thousand amperes, and time down to a few millionths of a second; and these, together with numerous other determinations, must be simultaneously effected without any possibility of failure or appreciable error. Considerable attention was therefore given to the design and layout of this apparatus for the Witton High Power Test Laboratory. In nearly every case the more important instruments have been designed and manufactured in the Development Department at Witton, and details of their construction are given briefly in this article.

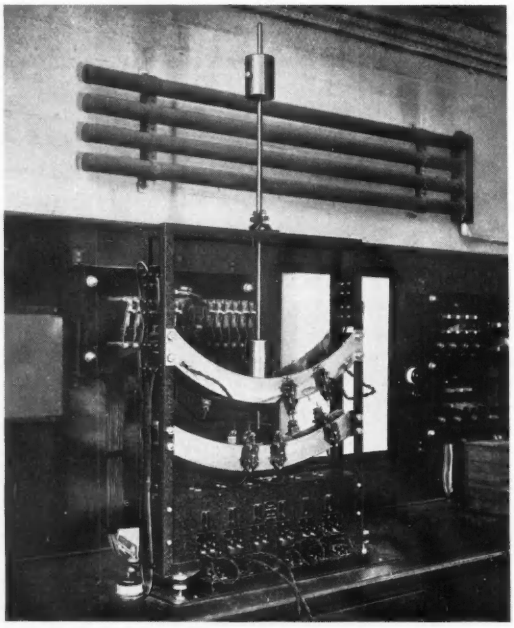


Fig. 49.—Contact pendulum in the control room of the observation house.

SHORT CIRCUIT TIMING.

During each short circuit test, the switching of the main circuit components and the recording apparatus has to be controlled to a time schedule which must be correct to within 1/100 of a second. This necessitates a very accurate automatic timing device, which must also be flexible in operation to allow for the wide range of time settings demanded by tests on various pieces of apparatus having different characteristics. The timing controller installed consists of a series of relay contacts which are actuated during a single swing of a master pendulum.

Twelve sets of contacts are provided, all arranged so that they may be either closed or opened by the action of the pendulum. Each moving contact consists of a silver ring recessed into an insulated barrel which slides axially in guides. Four fixed silver contacts are arranged to rub lightly on the barrel, the upper pair being connected together by the ring when the cylinder is latched against the operating spring. When the pendulum trips the latch contact between the upper pair is broken and is made between the lower pair. Since only a sliding contact is used any tendency to bounce is eliminated.

The twelve contacts are mounted on four sectors as shown in fig. 49, thus enabling the contacts to be set at very close time intervals, if required. The pendulum is of the compound type and is mounted on hardened steel points. It has an active swing of 50°, the sectors being scaled from 0—100 in half degrees. The period of the swing may be varied by adding jockey weights to the lower bob. Five weights are provided, these giving swings of 1, 2, 3, 4 or 5 seconds, a range which is ample for all usual testing requirements. To enable the pendulum contacts to be reset safely and adjusted between tests, a twelve pole contactor is provided for rapidly isolating all connected circuits.

Before the test the pendulum is latched to one side, the latch being tripped by a small electromagnet energized *via* a contact on the main oscillograph camera drum, so that the release of the pendulum is synchronized with the rotation of the oscillograph film to ensure that the record does not cross the join of the film.

As each circuit breaker tested has different

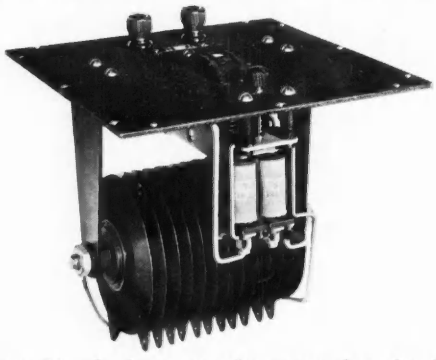


Fig. 50.—Cycle counter for measuring circuit breaker operating time delays.

operating time delays, it is necessary to measure these before the short circuit time schedule can be arranged. To enable this to be done quickly, a simple "cycle counter," fig. 50, has been made. It is operated from a 230 volt, 50 cycle controlled frequency supply, and consists of a scale graduated from 0—50 which is rotated by a standard telephone rotary switch mechanism energized through a half-wave metal rectifier. Connections are made to the test circuit breaker so that by opening and closing it, the operating delays can be read off in cycles, a method which is sufficiently accurate for all routine testing.

LOW FREQUENCY OSCILLOGRAPHS.

The records normally taken on the L.F. (or electro-magnetic) oscillograph are : volts, amperes, watts per phase, tank pressure, crossbar travel, and trip coil current. For special tests, a greater number of records may be required. It was therefore decided to install permanently an oscillograph giving twelve records on one film, this being sufficient for routine testing, and to make arrangements for running an existing portable 6-element oscillograph in parallel with it, thus enabling 18 records to be obtained for special tests.

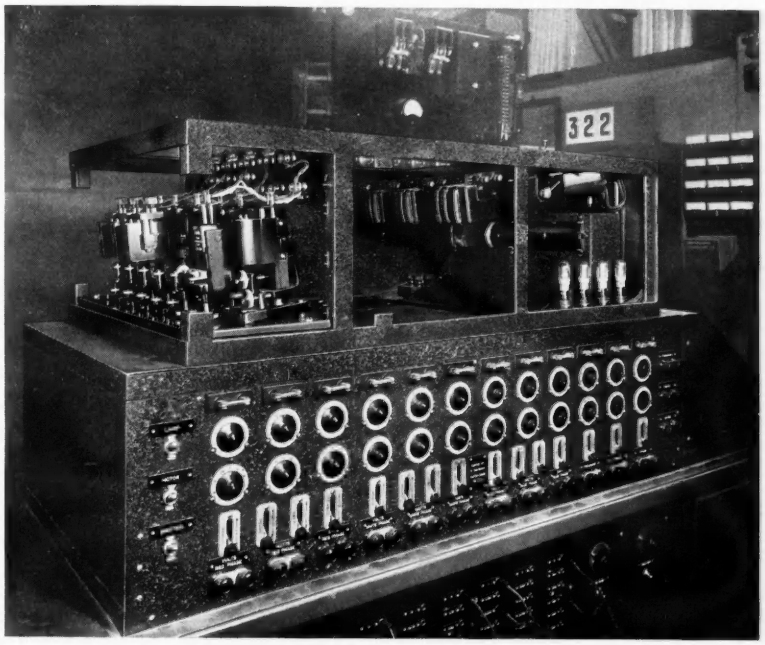


Fig. 51.—12-element electro-magnetic oscillograph for recording short circuit transients.

The design of the new 12-element unit, fig. 51, was based upon the experience gained with the 6-element portable oscillograph previously built for recording short circuit transients. Operation had shown that metal filament lamps were capable of giving sufficient light intensity for all purposes, and in addition to enabling the oscillograph to be made in a compact form they obviate loss of record due to arc lamp flicker, and require no attention during operation. Four 32-watt talking film exciter lamps are used to illuminate the twelve vibrators, the current being boosted by 25 per cent during exposure. The life of a lamp is over six months with normal daily use, and should a lamp fail during an exposure of less than $\frac{1}{2}$ second (the normal for short circuit testing), the filament will continue to glow sufficiently for the record to be obtained.

The optical system follows conventional practice, the lenses being mounted on an extension of the four lamp chambers. An electrically controlled shutter is located between the cylindrical condenser and the camera drum. The twelve vibrators are mounted on a bakelite panel which can easily be removed from the oscillograph for cleaning and inspection. Nine permanent-magnet and three dynamometer vibrators are used, the latter being arranged so that by exciting the field coils with direct current they can be used for recording any other component.

The camera drum fits into slides at the end of the oscillograph box. Four drums are provided, which are made of aluminium and take a film 12ins. wide by 19ins. long and although a special contact enables two or more separate records to be taken on one film, one drum is generally used for each short circuit test. Each drum is fitted with an automatic shutter which opens when it is placed on the oscillograph. The film is driven by a variable speed D.C. motor through rubber belts and large diameter reduction pulleys in order to provide constant and smooth speed over each revolution. A tachometer is fitted and the speed range of the drum is 10—480 r.p.m., covering all the short circuit durations normally required for testing.

Beneath the oscillograph are mounted resistances for adjusting the sensitivities of the vibrators, and changeover switches for connecting these either to the test circuit or to the calibrating board. Before and after each series of tests the vibrators are calibrated by applying measured values of volts, amperes or watts (obtained through potentiometers from batteries) and noting the deflections on a graduated screen which can be fitted into the camera slides.

Behind the oscillograph is mounted a plug selector panel through which any of the vibrators

can be connected to selected points on the test circuit. All connections to the latter are made *via* very flexible, requiring a minimum of maintenance and attention. Fig. 52 shows a typical record taken

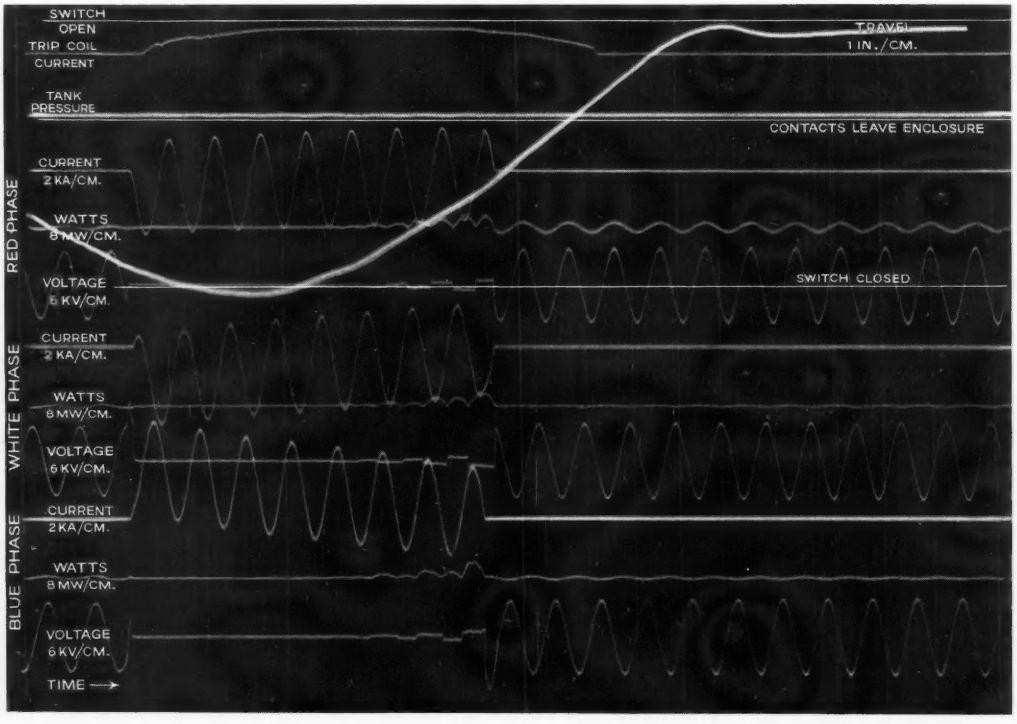


Fig. 52.—Typical oscillogram taken with the electro-magnetic oscillograph shown in fig. 51.

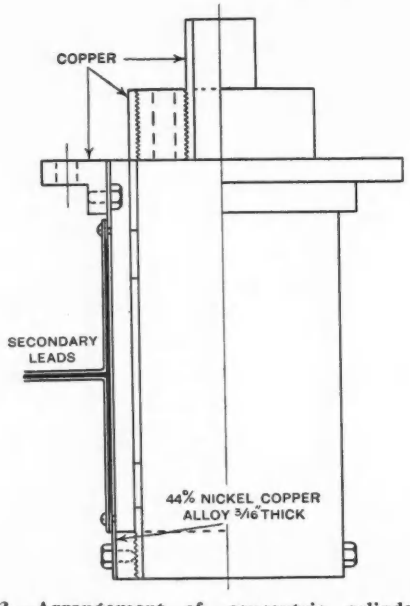


Fig. 53.—Arrangement of concentric cylinder non-inductive type shunt for measuring short circuit currents of range 20-200 kilo-amps.

screened concentric cables to obviate interference from the main circuit.

In operation the instrument has proved to be very flexible, requiring a minimum of maintenance and attention. Fig. 52 shows a typical record taken with the oscillograph. It shows the volts, amperes and arc watts per phase, together with tank pressure, trip coil current and crossbar travel of a circuit breaker during a "make-break" short circuit operation.

SHUNTS.

For the measurement of the short circuit current three shunts per phase are installed at the earthed star point in the machine room. Their ratings are as follows :—

20—200	kilo-amps.	R.M.S.	0.00005 ohms.
8—40	,,	,,	0.000125 ,,
1—10	,,	,,	0.001 ,,

Special care was taken to ensure freedom from errors due to skin effect, proximity effect of adjacent phases, stray fluxes and temperature variations. The two larger shunts are therefore of the concentric cylinder non-inductive type, as shown in fig. 53, and are arranged in a plane at right angles to the main bus bars. In addition, they are supported on a wooden framework removed as far as possible from the magnetic fields of the current regulating reactors. The smallest shunt is of the hairpin type.

Measurements carried out since the installation has been in operation have shown that the total

interference under the worst conditions of flux linkage is less than 0.25 per cent, which compared with the overall accuracy of oscillographic measurement can be regarded as negligible. All of the shunts are made of a material with a negligible temperature coefficient.

CURRENT TRANSFORMERS.

The current coils of the watt oscillograph vibrators require 5 ampere secondary current transformers for their excitation. Doubt regarding the accuracy of the output of a current transformer for recording asymmetrical current waves has often been expressed, but a series of tests on current transformers of different designs showed that ring type transformers with evenly distributed secondaries, when operated at low flux density, are quite satisfactory for routine use. For special tests where the greatest accuracy is required it is advantageous to demagnetize the iron before the test.

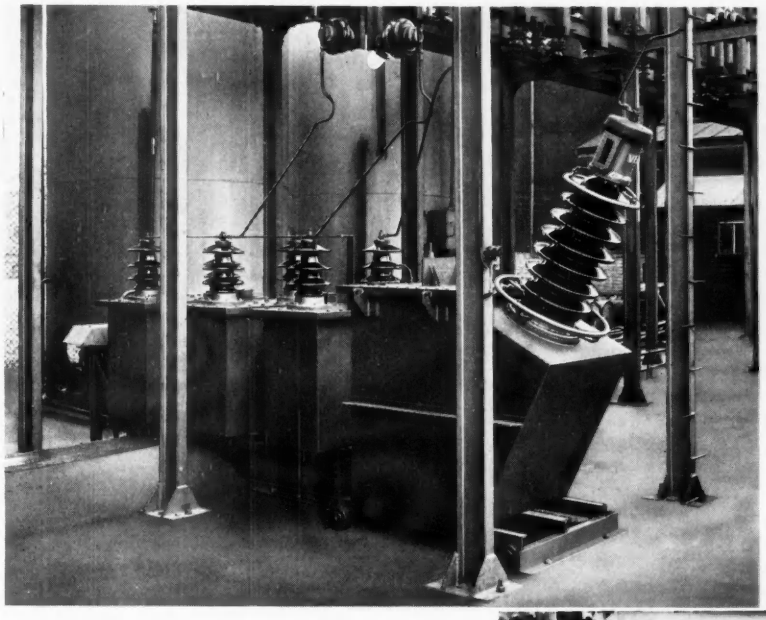


Fig. 54.—Outdoor potential transformers. On the right is the 88 kV/110 volt transformer, and behind the three dual ratio 22/44 kV to 110 volt transformers.

Two transformers are installed per phase, each having four ratios obtainable by series/parallel connection of the secondary windings. The ratios are:

1st current transformer 160/80/40/20 kiloamps. to 5 amps.

2nd current transformer 16/8/4/2 kiloamps. to 5 amps.

The iron cores are of stalloy stampings and the primary consists of a single copper tube 10 inches in diameter. Owing to the large number of secondary turns (32,000 for the 160,000/5 ratio) the secondary open circuit voltage is several thousand. To prevent danger to personnel and damage to the secondary cables in the event of a break in the vibrator circuit, a spark gap set to discharge at 500 volts is permanently connected across each secondary.

On account of the high open circuit voltage, it is impossible to demagnetize the high ratio current transformer with alternating current. A variable D.C. supply, which can be reversed smoothly, is therefore arranged so that by taking the iron through successively diminishing magnetization loops, any residual magnetization can be reduced to zero.

POTENTIAL TRANSFORMERS.

Potential transformers are installed for measuring the voltage at the generator terminals, and also across the poles of the circuit breaker under test. At the generator are three single phase transformers connected in star, the ratio being 22 kilovolts/110 volts. The secondaries supply the switchboard voltmeter in the Observation Room, and are also connected to the oscillograph selector plug board.

Behind the Test Bay and connected to the test switch terminals are three single phase 11 kV/110 volt transformers; while outside the building, and arranged so that they can be connected to either the 22 kV Test

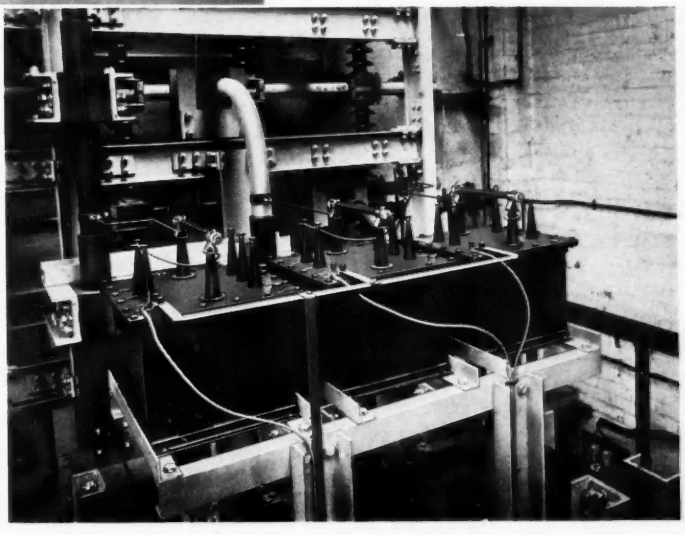


Fig. 55.—Three resistance type potential dividers installed near the maker switch in the generating station.

Bay terminals or the leads from the high voltage transformers, are three dual ratio transformers rated at 22/44 kV to 110 volts. For higher voltage single phase tests there is an 88 kV/110 volt transformer. The outdoor potential transformers are shown in fig. 54. All the transformers have series resistances

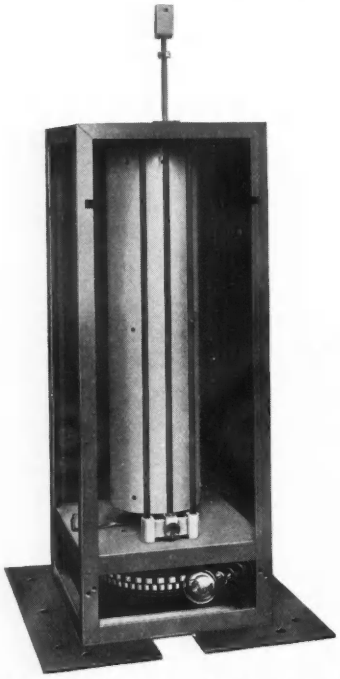


Fig. 56.—Mechanical recorder for recording the travel of circuit breaker contacts.

and are protected by high rupturing capacity fuses on the H.V. side.

POTENTIAL DIVIDERS.

When potential transformers connected in star with their neutral point earthed are used for recording circuit breaker recovery voltages on an insulated neutral supply, a zero displacement is introduced by the discharge of the generator capacity through the inductances of the transformers. To obviate this a set of three resistance type potential dividers have been installed, fig. 55. They consist of flat non-inductive resistance units, oil-immersed to obtain the requisite insulation. Each divider has a maximum resistance of 250,000 ohms, with tappings at each 50,000 ohms, and is rated for use up to 12.8 kV, this enabling them when connected in star to be used on 22 kV 3 phase tests.

At the earthed end of each divider is connected a 1,000 ohms resistance unit which is in parallel with the oscillograph vibrator circuit; thus, should the vibrator become open circuited, the maximum potential which can be imposed on the pilots is about 50 volts. Each divider is protected by a potential transformer fuse.

PRESSURE RECORDER.

Oil pressures are recorded on the oscillogram by means of two recorders which can be applied to either the tanks or the explosion pots. Each consists of a small laminated electro-magnet, the impedance of whose coil is varied by the deflection of a diaphragm subjected to the oil pressure. The magnet forms one arm of a balanced bridge circuit supplied with voltage at a frequency of 1,000 cycles from a valve generator. The output of the bridge is connected to an oscillograph vibrator, the envelope of the record being calibrated against pressure.

TRAVEL RECORDER.

The travel of the circuit breaker crossbar can be recorded on the oscillogram, the transmitter consisting of a potentiometer coupled to the crossbar. In order to increase the accuracy of arc length measurements from this record a supersensitive vibrator is used capable of giving a deflection up to 30 cm. A separate mechanical recorder, fig. 56, consisting of an aluminium drum 24ins. long by

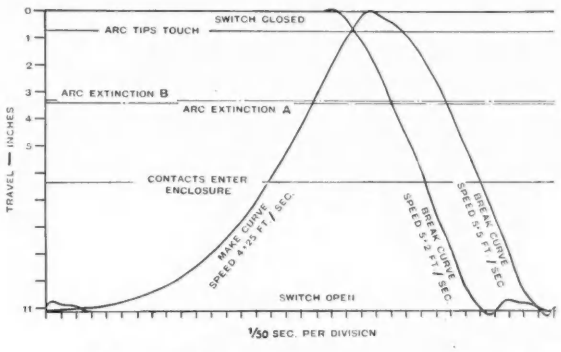


Fig. 57.—Record taken of contact travel by mechanical recorder in fig. 56.

6ins. in diameter rotated at constant speed by an electric motor, is also used in some tests. Paper is wrapped round the drum and this is marked by a pencil which is moved axially by a rod attached to the crossbar. Two drum speeds are used, *viz.*, 60 and 90 revolutions per minute. These are adjusted by a flyball governor and measured by a stroboscope attached to the drum and illuminated by a neon lamp energized from the 50 cycle operating supply.

Fig. 57 shows a developed record taken on this instrument, a "Break" and "Make-break" operation being recorded.

CATHODE RAY OSCILLOGRAPH.

For the study of the high frequency restriking voltage transients, a cathode ray oscillograph made by the Cambridge Instrument Co. Ltd., specially for this purpose has been installed. The instrument is housed in a room which is lined with ¼in. steel

plates to prevent interference from the test circuit during heavy current tests. The instrument is shown in fig. 58.

The photographic film on which the record is taken rotates at speeds up to 3,000 r.p.m. within the main vacuum of the oscillograph. The film is 12.5 cms. wide and 2 metres long, so that at full speed when one 50 cycle wave is extended to the full length of the film, high frequency oscillations up to 200,000 cycles per second are easily readable. A D.C. shunt wound motor arranged to give speeds from 50—3,000 r.p.m. drives the film drum through a two stage gland, the intermediate section being maintained at a pressure of about 0.1 m/m. of mercury by a duplex rotary oil pump. The main body of the oscillograph and the camera drum are evacuated to a pressure of 0.001 m.m. of mercury by two four stage mercury diffusion pumps, which are backed by a single stage rotary oil pump. Two traps cooled to $-60°C$. by carbon dioxide snow are used to condense mercury vapour and prevent water vapour given off by the film from appreciably reducing the pumping speed.

The discharge tube itself is made of glass and is of the cold cathode type requiring from 10—70 kV D.C. excitation. This is provided by a transformer and valve rectifier, fig. 59, which will give 80 kV D.C. output at 15 milli-amps., the transformer being also used for flash testing oil samples taken from circuit breakers under test. The air pressure in the discharge tube necessary to produce a steady cathode beam is regulated by a special leak consisting of a small piece of porous material which is normally sealed by a layer of mercury, but which can be uncovered by the rotation of a metal disc holding a similar piece of porous material.

Upon emerging from the pinhole in the anode block, the cathode beam enters a trap from which it can be deflected by the application of about 300 volts D.C. to the de-trapping plates. In this way the retrograde rays are prevented from passing through the trap and fogging the film before the true exposure. Below the trapping section is mounted a concentrating coil for focussing the beam to a spot upon the film.

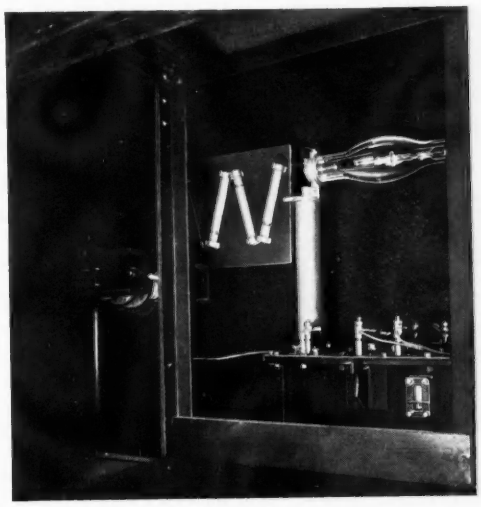


Fig. 59.—Transformer and valve rectifier for giving 80 kV direct current.

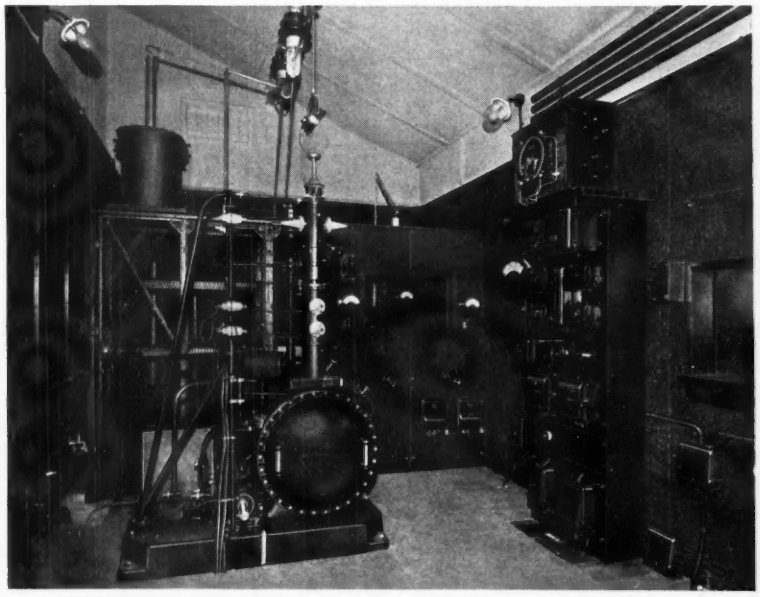


Fig. 58.—Cathode ray oscillograph room. On the right is the L.V. control panel, and at the back the H.V. control board.

In the section immediately above the camera are mounted two sets of electrostatic deflection plates for bending the beam in a plane at right angles to the direction of rotation of the film. The top pair are connected to the test circuit through a screened concentric cable and a capacity potential divider. The other pair of plates is used when an extra long record is required and traverses the beam across the film by the discharge of a condenser through a saturated valve, thus preventing records taken on successive revolutions of the film from obscuring each other.

Immediately above the film is a hand operated shutter upon the back of which is a fluorescent screen and scale for calibrating the deflection, this being viewed through a glass window let into the side of the deflection section.

The synchronization of the cathode ray oscillograph record with the short circuit is obtained by operating the de-trapping circuit from the main timing pendulum *via* a high speed relay. By virtue of the large capacity vacuum pumps employed, the time from loading the film to taking the record is only 30 minutes. Fig. 60 shows a portion of a 2-metre record taken on the oscillograph, during a three phase short circuit test, and shows the restriking voltage on the first phase to clear. Reading from the left, the first oscillation is that which occurs when that particular phase clears, and the second oscillation is that which occurs on the same phase when the other two phases clear a fraction of a cycle afterwards. This should be compared with fig. 61 which shows the same voltage recorded simultaneously on the L.F. oscillograph.

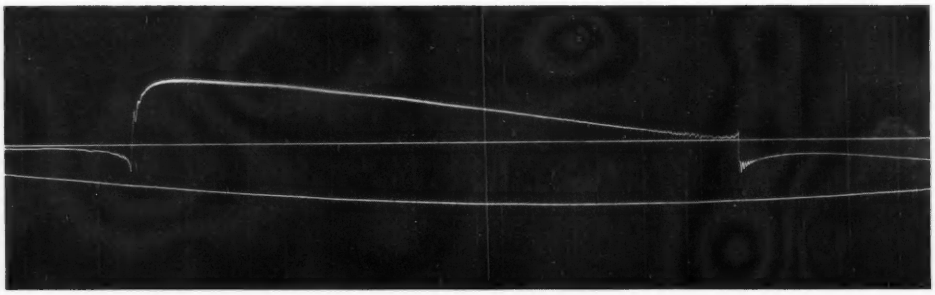


Fig. 60.—A section of a 2-metre record taken on the cathode ray oscillograph shown in fig. 58.

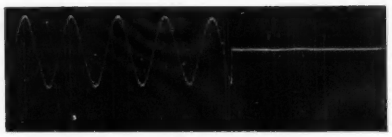


Fig. 61.—Record of the same voltage as given in fig. 60, but taken on an electromagnetic oscillograph.

The above instrument takes single phase records only; for three phase testing a second cathode ray oscillograph has been ordered. This oscillograph will take three records simultaneously side by side on one film 12ins. wide by 36ins. long.

NATURAL FREQUENCY MEASUREMENTS.

The rate of rise of the restriking voltage across the circuit breaker terminals depends to a large extent upon the natural frequency of the test circuit, which consists principally of inductance and capacity in parallel, located in the generator, reactors, transformers and bus bars. Each portion of the circuit has its own natural frequency, the complex resultant appearing at the circuit breaker terminals. For each combination of generator, reactor and transformer switching there is a different resultant. To assist the interpretation of cathode ray oscillograms, a knowledge of these natural frequencies is useful. In order to measure them, a variable frequency oscillator having a range from 10,000—200,000 cycles per second has been built this being used in conjunction with a gas focussed cathode ray tube set up as a resonance indicator.

A portable universal bridge is also used for measuring the various inductances and capacities so that measurements may be amplified by calculation.

Power Plant Reorganization at Hamstead Colliery.

By B. S. PELTON, B.Sc. (Eng.).

Fraser & Chalmers Resident Engineer, Midland Area.

Fig. 1.—General view of Hamstead Colliery before reorganization of the power plant was started.

Fig. 2. (right).—View of the colliery after the reorganization. The new power house and modified legs of the head frame are shown.

INTRODUCTION.

HAMSTEAD Colliery is situated about four miles north of the centre of Birmingham, and works the South Staffordshire thick seam, on the eastern side of the boundary fault. Coal was first mined at this pit in 1875, when the shaft which is now known as the auxiliary shaft was used. About 1881, what is now the main shaft was sunk, and the winding engine then installed remained in service until the recent reorganization of the plant. The coal is situated at a depth of 1,800 feet, and the main shaft through which all the coal is drawn is 1,740 feet deep between decking levels. From time to time the plant has been extended, and screening and washing plants have been installed.

In 1934 the Directors of Hamstead Colliery Co., (1930), Ltd., decided to complete the electrification of the colliery, and to modernize and extend their power plant. The main part of this comprehensive scheme was entrusted to The General Electric Co., Ltd., and the object of this article is briefly to describe the scheme and the manner in which it was accomplished.

REORGANIZATION SCHEME.

Before the new plant was installed the main haulages for the pit were steam driven and were

situated on the surface, with the ropes passing down the shaft.

Electric power for the mine and surface was taken partly from a bulk supply and partly from a

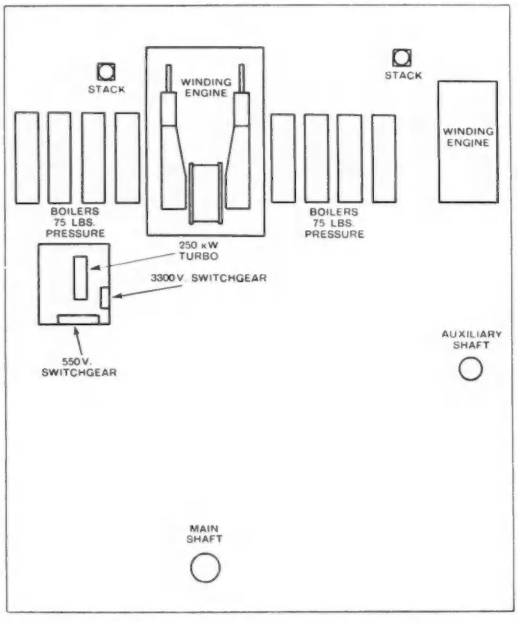


Fig. 3.—Plan of old winder and power house.

250 kW turbo-alternator. The winding engine which had operated for over 54 years was supplied with steam at a pressure of 70 lbs. per sq. in.

Fig. 5.—The pit head frame showing the new legs in position prior to removing the old legs.

Compared with modern equipment its steam consumption was excessive.

The main parts of the reorganization therefore comprised :

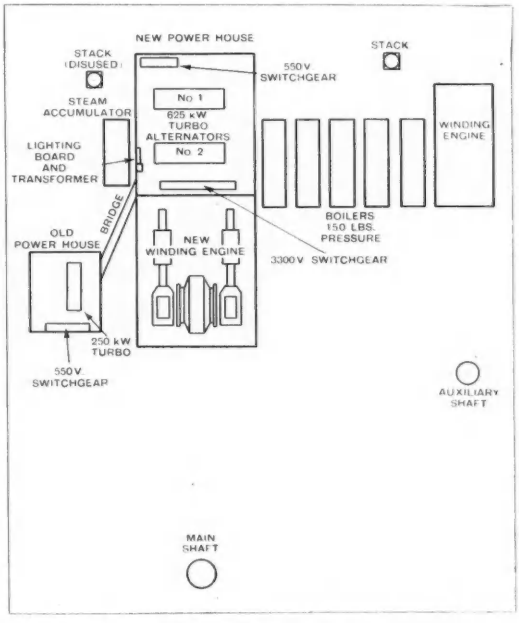


Fig. 4.—New winding engine and power house showing turbo-alternators and 3,300 volt switchgear.

(*a*) Modernizing the boiler plant, and raising the steam pressure to 150 lbs. per sq. in. gauge, 150 degrees superheat.

(*b*) The installation of a new steam winder.

(*c*) The installation of two 625 kW mixed pressure turbo-alternators.

(*d*) The installation of electrical haulages to replace the old steam haulages.

(*e*) The provision of new switchgear, transformers and shaft cable.

The external appearance of the colliery before and after the reorganization scheme was completed is shown in figs. 1 and 2. Figs. 3 and 4 show a plan of the old winder and power house, and the new arrangement respectively.

It will be seen that the original winder house was extended and that the new turbo-alternators were installed in the space originally occupied by the old winding engine, so that now the winding engine and generators are under one roof.

It is unusual in this country to find a colliery winder and generating plant installed in the same building, but the scheme is convenient and efficient, although in this case such an arrangement was adopted to utilize the space previously occupied by the old winder, thereby saving building costs.

A condition applying to the whole plant reorganization was that the normal work of the colliery should not be disturbed. It was therefore necessary to install the new engine before the old one was taken out. The new engine had to be erected in front of the old one and as close to it as possible so that adequate rope leads were obtained. To achieve this, it was necessary to install the new engine at a lower level with its tail guides in chases cut in the brick foundations under the beds of the old engine. It was also necessary to replace the existing back legs of the head frame with new legs at a steeper angle.

The first stage consisted of building the foundations for the new engine and for the extended engine house. This work had to be completed before alterations could be started on the head frame. The replacement of the legs of the head frame was a difficult task, as winding could not be interrupted except for two days at weekends. New legs were therefore added to the existing structure and the old legs subsequently removed. Fig. 5 shows the new legs in position, prior to the removal of the old legs.

The next step was the erection of the steel frame of the winder house extension and the installation of the gantry and overhead crane. As soon as this was completed the new engine was installed as illustrated in fig. 6, which shows the new engine partly completed, and in the background the drum of the old engine which at that time was being used.

On completion of the new winder a holiday weekend was used for changing over. The old winding ropes were taken off and new ropes of the locked coil type fitted to the new winder. The new engine was put into service on the day following the holiday, raising full pit output. The new engine in its complete condition is shown in fig. 7. A view of the winder during assembly at Fraser & Chalmers Engineering Works is shown in fig. 8.

The old engine was next dismantled and removed through the back of the engine house, and the old engine foundations were modified to accommodate the two new 625 kW mixed pressure geared turbo-alternator sets which are shown in their completed form in fig. 9.

NEW WINDING ENGINE.

It was decided to replace the old winding engine with a Fraser & Chalmers high pressure duplex steam winder working at a pressure of 140 lbs. gauge, 150° F. superheat, and exhausting through an accumulator to the steam turbines, which are described later. The new steam winding engine is of somewhat smaller dimensions than the old winder,

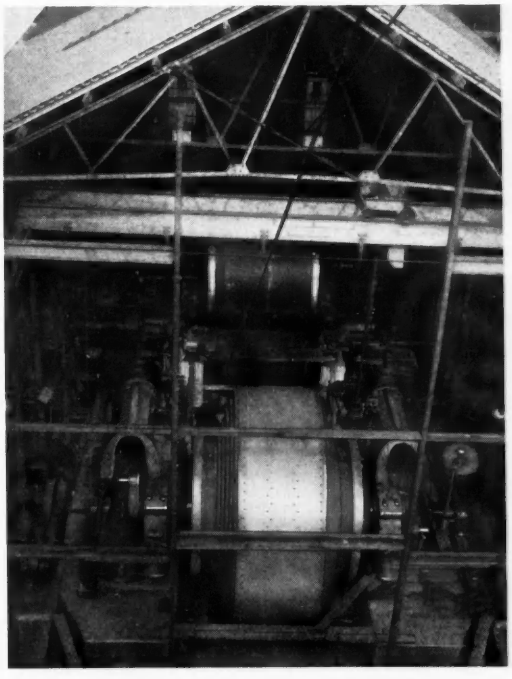


Fig. 6.—Installing the new winding engine. The drum of the old engine is seen in the background.

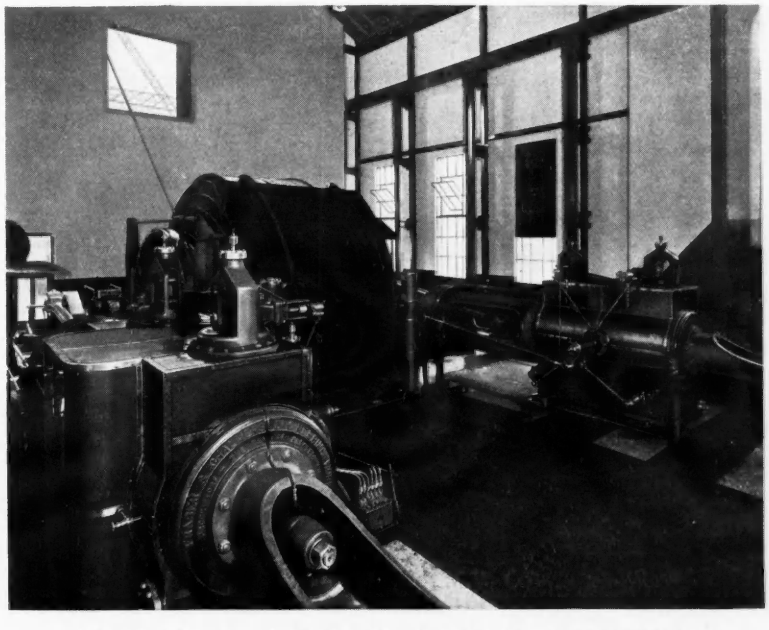


Fig. 7.—The new winding engine installed in the power house.

having cylinders 30ins. × 60ins. and a cylindro-conical drum, 11 feet/20 feet in diameter. The shaft has a vertical depth of 1,740 feet and the engine is designed to complete its run from start to stop in 45 seconds when handling a nett coal load of 3 tons 12 cwts. The new engine is fitted with steam valves of the double beat drop type and Corliss exhaust valves. It is provided with the Fraser & Chalmers patent slow banker which automatically trips the over-winder in the event of the speed being too high during the last few revolutions of a wind. As the cages approach bank, the speed at which the over-winder is tripped is automatically decreased. It is obvious that higher speeds can be used when winding minerals than when winding men. The slow banker is therefore arranged so that by the setting of a lever in the driver's cabin, the over-winder is tripped over a range of slower speeds. On operating this lever a lamp signal shows that the over-winder is set for men. The speed of the engine during the middle of the wind is controlled by the well known Whitmore over-winder.

The drum of the engine comprises two cast iron end-cheeks carrying a cylindrical barrel grooved for the rope and heavily reinforced by internal rings, no internal spiders being used. Spiral scrolls are cast integrally with the drum cheeks, this construction being much more satisfactory than a built up conical portion in which the scrolls are secured by rivets which frequently work loose under the heavy stresses imposed during winding.

The post brakes work on ventilated brake paths on the drum and are operated by a steam brake engine and a weight. The steam pressure in the brake engine cylinder acts against the weight and is controlled by the driver's brake pedal. The braking force is thus variable at will and in the event of the steam pressure failing, or being cut off in the case of an overwind, the brakes are automatically applied. The engine is provided with Allen straight type link motions. A wayshaft connects the two link motions and reversing is effected by means of a steam reversing engine coupled to a lever on this shaft.

POWER HOUSE EQUIPMENT.

Each of the two turbines in the power house runs at a speed of 6,000 r.p.m., and is coupled through reducing gears to a 625 kW alternator which runs at 1,500 r.p.m. and generates current at 3,300 volts, 3 phase, 50 cycles. The turbines are of the Fraser & Chalmers impulse mixed pressure type.

Each turbine exhausts to a separate surface condenser which is provided with a steam-operated air ejector, and vertical spindle circulating and extraction pumps mounted on a common shaft and driven by a vertical spindle motor. The circulating water is drawn from reservoirs through an existing 16in. diameter main and is returned to the reservoirs after having been pumped through a cooling tower.

It will be seen from this illustration that the cooling tower is not placed over the reservoirs, but is built over a sloping reinforced concrete tray which leads the water into the reservoirs. This construction

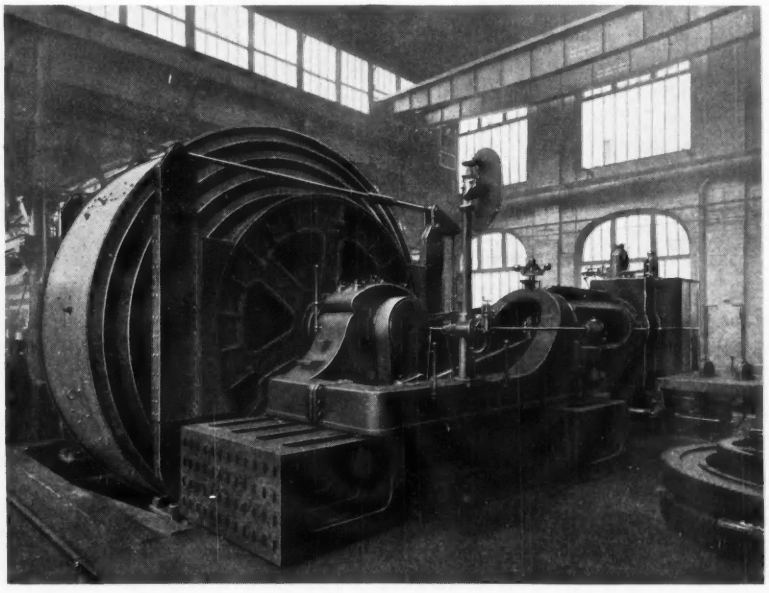


Fig. 8.—The new winding engine during assembly at Fraser & Chalmers Engineering Works.

was adopted as the reservoirs could not be drained to allow foundations to be put in, also, because the beds of the reservoirs are puddled and it was considered inadvisable to disturb the puddle.

Five new Lancashire boilers, operating at 150 lbs. pressure replace the eight old boilers which operated at 75 lbs. pressure. One of these five new boilers is used for stand-by purposes.

It is interesting to note that all the electrical load is now generated at the colliery; also that the electrical load has been increased by about 300 kW.

The s itchboard controlling the alternators and the 3,300 volt distribution is placed parallel to the turbo sets as shown in fig. 4. It is of the high tension steel plate cubicle type and is illustrated in fig. 10. Before describing this switchgear in

detail it is proposed to give a brief description of the switching system at the colliery.

Referring to fig. 4, a building marked "Old Power House" is shown which contains the old

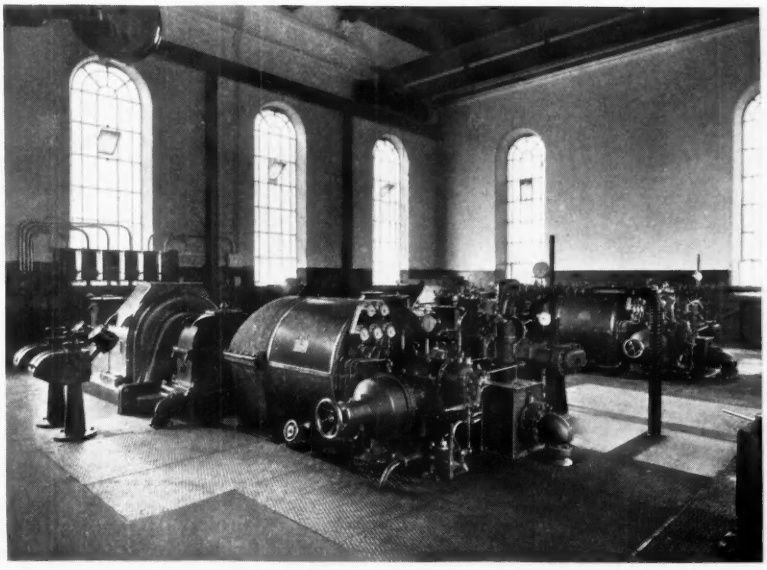


Fig. 9.—Two 625 kW, 3,300 volt, 6,000/1,500 r.p.m. mixed pressure geared turbo-alternators.

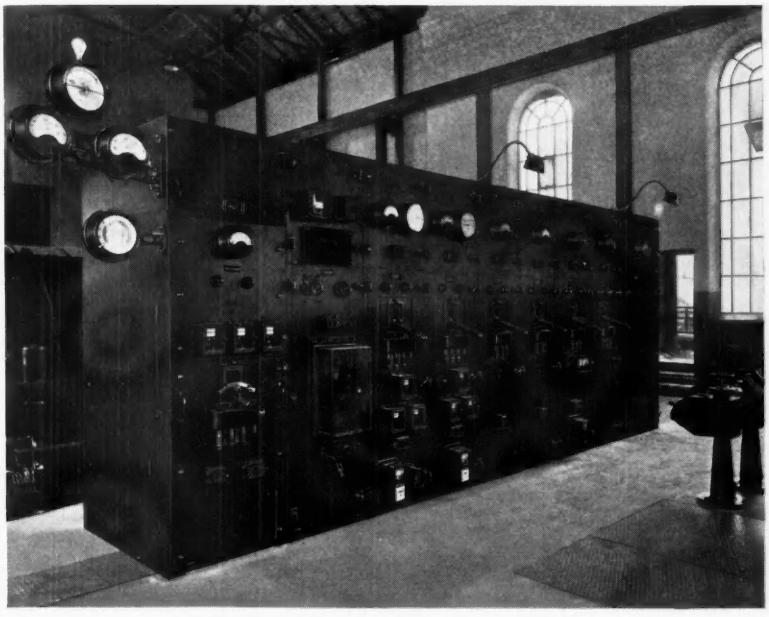


Fig. 10.—3,300 volt steel plate cubicle switchboard in the new power house.

250 kW turbo-alternator previously mentioned, generating at 550 volts. The old power house also contains switchgear and transformers. The surface distribution was carried out at 550 volts, while the pit was supplied with current at 3,300 volts by means of a step-up transformer. A bulk supply at the higher voltage was also brought in to the old station.

It was decided to retain the surface distribution switchgear in the old power house and to connect it through transformers by an interconnecting feeder to the high tension board in the new station. This feeder was connected through a new 357 kVA transformer installed in the old power house. In addition, the pit feeders are controlled from the new high tension board in the new power house.

Originally, it was proposed to cut out the bulk supply entirely, but it was finally decided to retain this supply for very small loads at weekends and holidays. This supply is now brought to the 3,300 volt board in the new power house. Provision is made to run the old 250 kW set and the two new 625 kW sets in parallel, and to allow synchronizing to be effected from both old and new power houses.

During periods when it is known that the load will not exceed 250 kW the whole colliery is fed from the 250 kW alternator through the existing transformers, and as these are delta wound on the high tension side no neutral point is available. Earth leakage protection on the shaft cable and mine equipment would thus be inoperative, and an artificial neutral is therefore provided through an earthing transformer on the 3,300 volts bus bars, so that the system is earthed under all conditions.

A single line diagram of connections is given in fig. 11. From this diagram it will be noted that panels are to be added to control the high tension side of two existing 145 kVA transformers which have been moved into the basement of the new power house. The low tension side of these transformers will be connected to a low tension board in the new power house (which controls power and boiler house auxiliaries, etc.), and through this board to low tension switchgear in the old power house. With this arrangement a standby power supply is provided

for the interconnecting feeders and transformers.

The 3,300 volt switchboard installed in the new power house at present has nine panels, comprising :

2—Alternator panels.
1—Interconnecting feeder panel (between old and new power houses).
2—Pit feeder panels.
1—Lighting transformer panel.
1—Bulk supply incoming feeder panel.
1—Tirrill voltage regulator panel and synchronizing gear.
1—Earthing transformer and leakage indicator panel.

Oil circuit breakers of 50,000 kVA breaking capacity are fitted and are of the manually-operated free handle type, with three overloads. Control pedestals are provided for alternator field control. The lighting distribution system at the colliery surface is carried out at 110 volts and a lighting transformer and ironclad distribution switchboard are mounted in the power house ; these can be seen in the background of fig. 9.

SHAFT CABLE.

In view of the larger electrical load now carried below ground, a new shaft cable has been provided and consists of a Pirelli-General high tension three core 0.15 sq. in., Sotonite-insulated cable, double wire armoured, double hessian taped and served. This finish will withstand the possible corrosive action of any water in the shaft.

In erecting the cable, use was made of the ordinary cages. A drum of cable was placed in the lowest of the three decks and the cage lowered slowly, the erectors working from the middle deck. On account of the limited size of cable drum which could be accommodated in one deck, three lengths of cable had to be used. The cable is cleated to the shaft every 25 yards, and as there are no suitable insets in the shaft, vertical joints are made. In each case these joints are made six yards above a cleat so that as little weight as possible is supported by the joint itself. The cable was erected at weekends, and here again the ordinary working of the shaft was not interfered with in any way.

HAULAGES.

The old steam haulages mentioned at the beginning of this article were replaced by electrically driven haulages in the pit and a further electric haulage was installed. One 100 h.p. and two 200 h.p. haulages were supplied for this purpose.

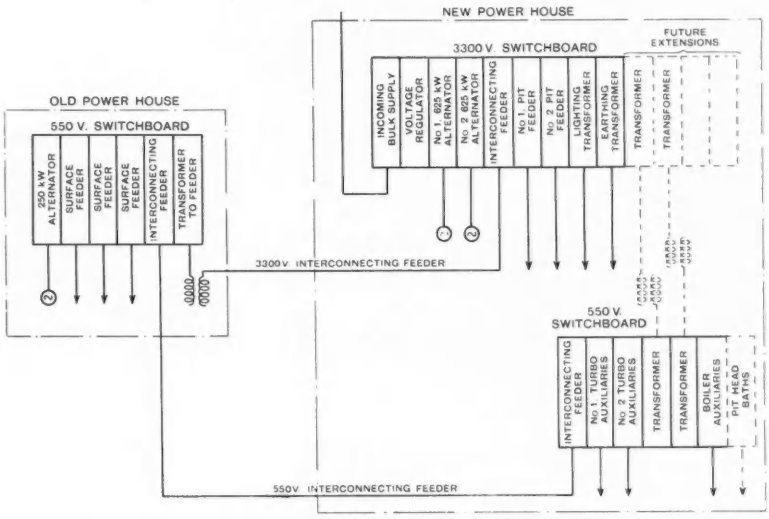


Fig. 11.—Single line diagram of connections for the switchboards in the old and new power houses.

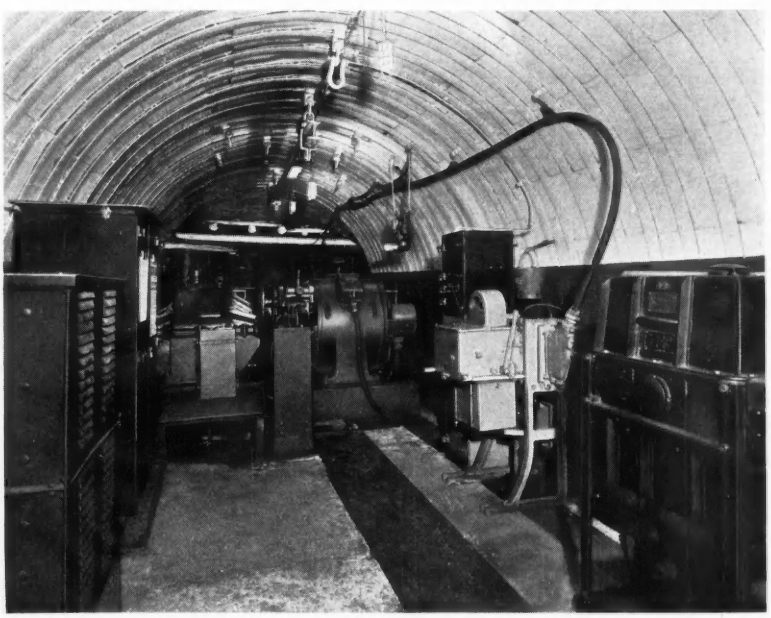


Fig. 12.—200 h.p., 3,300 volt haulage motor and control gear installed near the pit bottom.

The 100 h.p. haulage draws tubs from the workings along practically level roads for a distance of about 2,400 yards. The tubs from this and another haulage are then transferred to the rope of a 200 h.p. haulage.

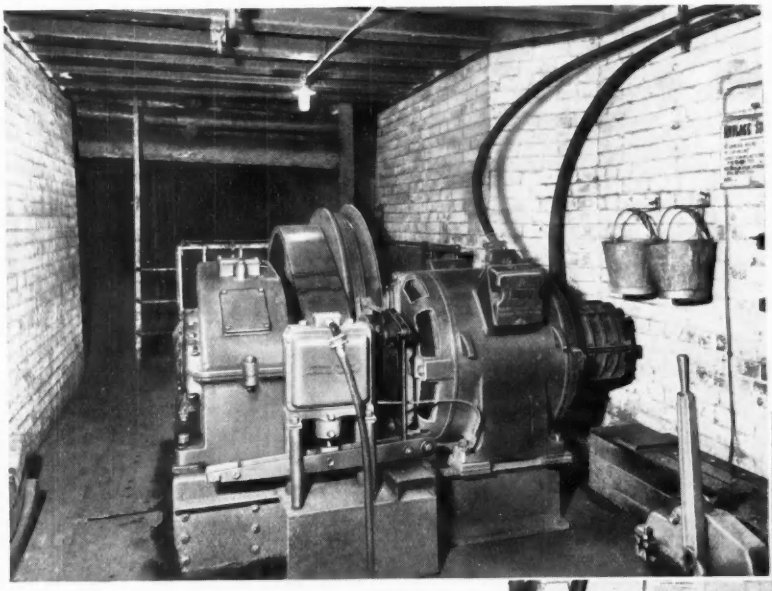


Fig. 13.—100 h.p., 3,300 volt haulage motor, 1½ miles from the bottom of the shaft.

This 200 h.p. haulage is installed near the pit bottom, and hauls tubs of coal along a main road for a distance of about 2,200 yards. This road is by no means level, the maximum gradient being one in six. A 1⅜ in. diameter rope is used to haul the tubs, and the duty on this haulage is probably the severest imposed on any haulage in the South Staffordshire coalfield.

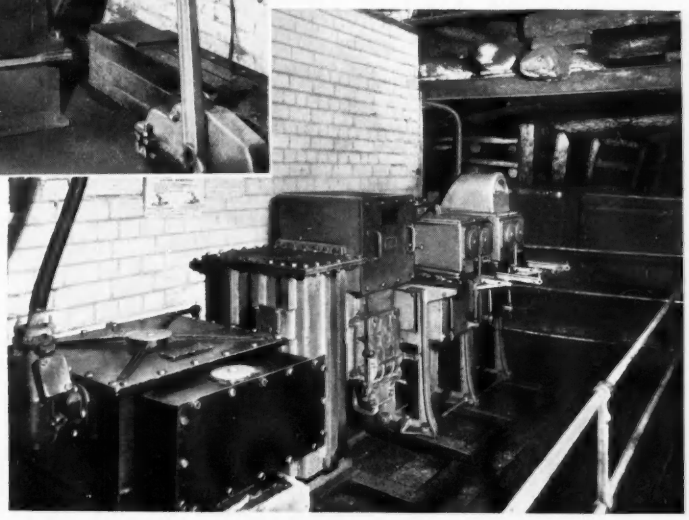


Fig. 14.—Control gear for 100 h.p. haulage motor shown in fig. 13.

This haulage is shown in fig. 12 and comprises an enclosed ventilated slipring induction motor, coupled through gears to a 7ft. diameter surge wheel, a large friction pulley giving a rope speed of 1¾ m.p.h. The speed reducing gears are in three stages, the first two being totally enclosed in a cast iron case and the gears running in an oil bath. The third reduction is open except for the provision of suitable guards. The teeth of the first reduction gears are of the double helical type, the subsequent reductions having straight cut teeth. Post brakes, operating on brake paths attached to the surge wheel, can be applied rapidly by means of a falling weight operating on the levers. Shock caused by sudden braking is avoided by the provision of an oil dashpot controlling the application of the weight. The whole equipment is mounted on a fabricated steel bed frame.

Flameproof motors are not required in this part of the mine and a ventilated motor has been employed for this drive.

The control gear for this haulage comprises a main oil switch, stator reverser and master controller, together with a single phase transformer to supply power for the various no-volt and operating coils and also for lighting. This transformer is controlled by a separate isolating switch and fuses.

The main switch is provided with three overload releases, and no-volt trip, and is electrically interlocked with the control equipment. The stator reverser is of the oil-immersed contactor type, and the rotor controller of the air-break contactor type. The latter has five accelerating contactors which in turn cut out steps in a suitably rated resistance, current limiting relays being provided for governing the rate of closing of the contactors irrespective of the rate which the master controller lever is moved. The master controller is of the drum type, provided with a push button to trip the main switch in case of emergency. For rope examination purposes, the resistance is rated to give a continuous creeping speed of quarter full speed against one-third full load torque. The safety of this equipment is secured by door interlocks. Earthing bridges are provided for the oil circuit breakers to enable cables to be earthed through the switches during maintenance or repairs. The second 200 h.p. haulage is a duplicate of the one described and is installed near the pit bottom. It acts as a main road haulage for a new area which is being developed.

In the case of the 100 h.p. haulage the first two totally enclosed gear reductions are mounted on ball and roller bearings, and the surge wheel is 6 feet in diameter. This haulage is installed about 1½ miles from the bottom of the shaft, where more dangerous conditions exist. The slipring cover of

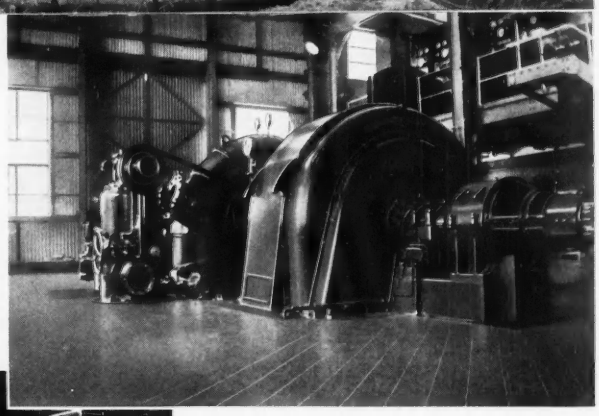
the motor and all control gear are therefore of the flameproof type. This haulage and its control gear are shown in figs. 13 and 14; from these it will be seen that no post brakes are fitted to the surge wheel, but that solenoid operated brakes are installed acting on a drum adjacent to the motor coupling.

CONCLUSION.

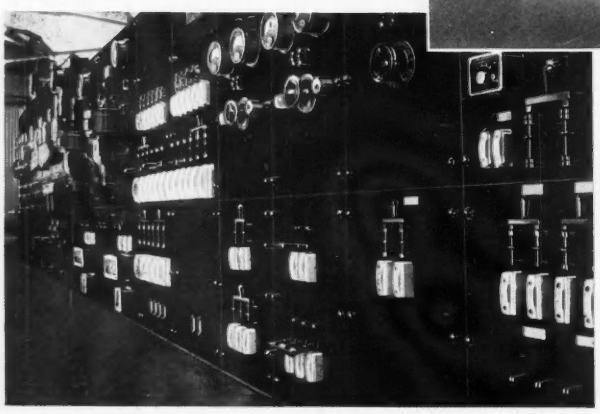
The equipment described has been in successful operation for periods ranging from eight to fifteen months according to the sequence of installation.

In conclusion, the author wishes to record his thanks to the Directors of Hamstead Colliery Co., (1930), Ltd., for their kindness in allowing the publication of this article, and to the Management for their co-operation in its preparation.

Pangani Falls Power Scheme.



A new hydro-electric plant has recently been installed at the Great Pangani Falls, near Tanga, Tanganyika. This plant, which has been under construction since 1933 at a cost of £250,000, is designed to ensure a supply of cheap power to Tanga and also to the many large sisal estates (employed in the growing and decortation of sisal for twine and cordage) situated in the Pangani River watershed.



The illustration at the top shows the 6ft. diameter steel pipe which conveys water from a forebay in the river to the power house, giving a head of approximately 320ft. One of the two 2,500 kW hydro-electric units installed in the power house is seen in the middle illustration, while on the left is shown the control board.